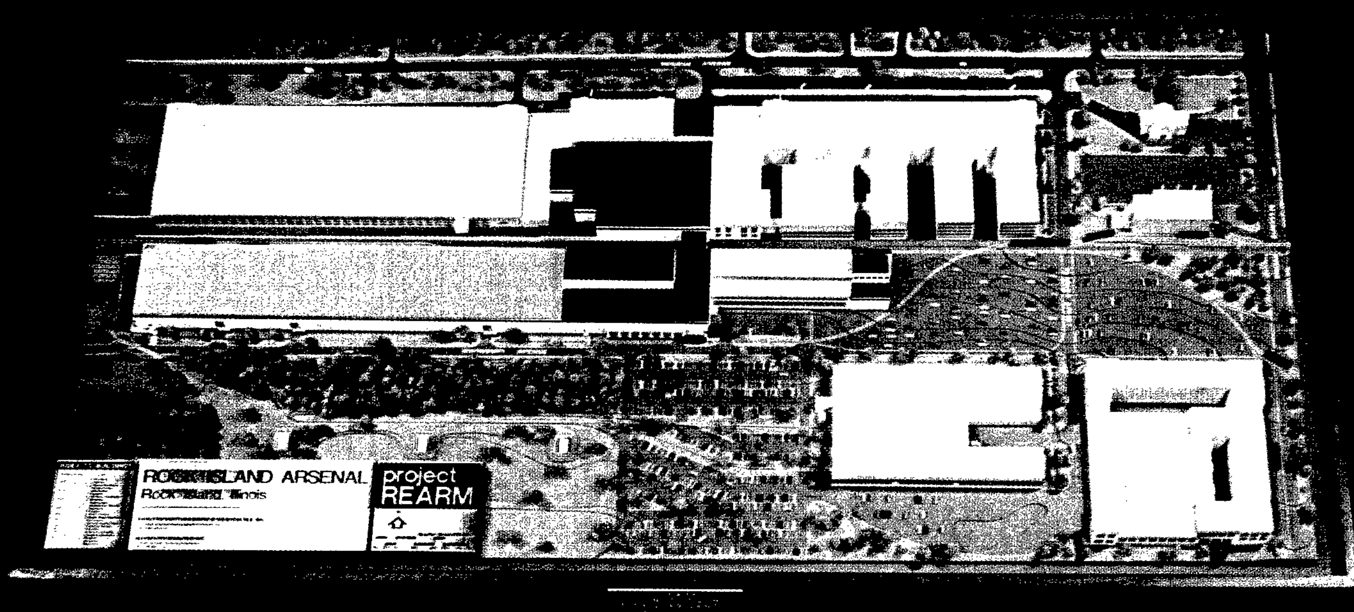
US Army

ManTech Journal

Preparing A Solid Base

Volume 8/Number 1/1983



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Contents

ABOUT THE COVER:

The Front Cover: This color photograph of a model of the proposed production facilities of the U.S. Army Materiel Development and Readiness Command at Rock Island Arsenal, Illinois illustrates various modules that will be added during the next five years of plant modernization. Specific details are discussed in the article beginning on page 3. **Back Cover:** The upper photograph depicts the Rock Island production facilities around the turn of the century, with long rows of machinery driven by water power from the Mississippi River. The lower photograph shows several proposed processes that will be used at the Arsenal following its modernization. Automated, highly sophisticated manufacturing techniques will provide new levels of efficiency.

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Comments by the Editor

RAYMOND L. FARROW

The year 1983 will be remembered as a year of readjustment by all of us who are involved with activities related to U.S. Army manufacturing technology and improving the production base. The $120 million appropriation for manufacturing technology was cut to $50 million. Furthermore, the program has been funded under the research and development appropriation. This change of emphasis from applied technology to advanced development will be the subject of much conjecture during the coming months, and its long term effect ultimately may change the entire character of the Army's mantech effort.

However, two aspects of the current program will not be affected by the impending changes and are subjects of articles in this issue of the U.S. Army ManTech Journal. In the first article following this commentary, the Rock Island Arsenal portion of project REARM of the U.S. Army Materiel Development and Readiness Command is described. This long term program was begun at Watervliet Arsenal in 1979 and is being extended to Rock Island Arsenal in a major effort by the Army to prepare these two critical military production facilities for rapid mobilization capability and greater efficiency of operation. This is the first thorough, well planned modernization of these two arsenals which have produced weaponry for our nation during periods of conflict spanning our entire history. When the program is completed at the end of 1987, the arsenals will be able to cope better with sudden demands on their production capabilities and will operate in a more cost effective manner than at any time in their past. This multiyear effort escaped any reduction in its funding, and plans that have been completed during past years will be completed as scheduled.

Another article in this issue discusses the procedural changes in the U.S. Army Aviation Research and Development Command's programs to implement new techniques developed under the Command's manufacturing technology projects. The AVRADCOM procedure is thoroughly spelled out for potential contractors and emphasizes letters of intent to implement a specific technology. A notable characteristic of the procedure is the early participation in the planning and execution of a new program by all departments and officials at all levels who ultimately will be involved with the product/project. A total engineering package supported by thorough economic analysis and cost accountability, the procedure is initiated by a Project Work Directive which is briefly outlined at the end of the article. This Continuation or Supporting Sheet spells out in detail all the items and services required of a potential contractor to AVRADCOM, including even a requirement for an article to be prepared for submittal to the U.S. Army ManTech Journal describing the benefits of the project results.

We again feature extensive coverage of ongoing Army mantech projects in this issue, and this group of brief status reports brings us up to date with all the past projects that form the basis of the IBEA computer data bank. We will rely in the future on periodic

updates of continuing projects and reports of new starts that are provided semiannually by IBEA. We will continue to present a full spectrum of project briefs, which have proven highly informative to readers.

Quality control during the manufacture of the Army's 155-mm rocket assisted projectile has received a big boost by the development of a new automated optical inspection system by Chrysler-Huntsville for the U.S. Army Armament Research and Development Command. The new system will enable faster, more accurate inspection of the interlock between the projectile and warhead of these items. This system is described in an article on page 25 of this issue.

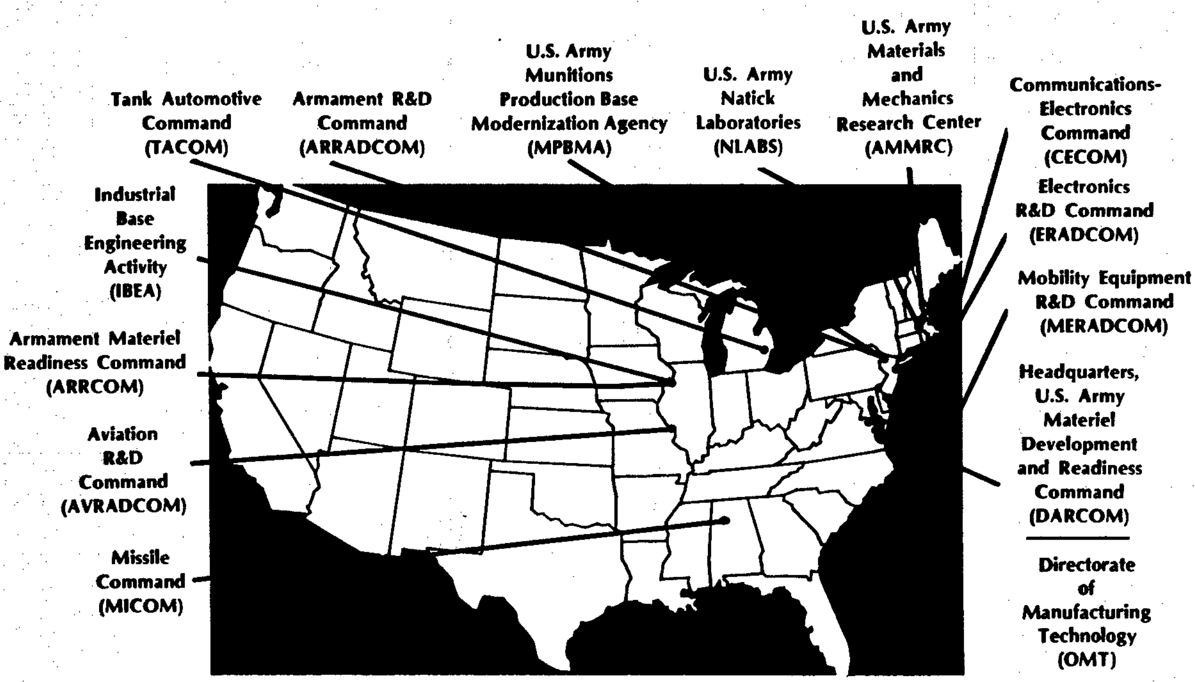
A spectacularly successful MM&T project to develop the technology to manufacture a traveling wave tube featuring a specialized circuit is described in an article on page 28. The project involved three phases, the first of which brought such success that less stringent design considerations were involved during the ensuing two phases of the project. That type of occurrence often is experienced by workers on the Army's mantech projects and reflects the flexibility of the programs.

Another quality control project for the U.S. Army Armament Research and Development Command that enabled production of microchannel plate electronics equipment to be improved is described in an article on page 37. The documentation developed has had a beneficial impact upon customer relations due to the availability of a more effective process procedural manual. Acceptance rates of units received from the manufacturer have climbed, and even higher rates are expected.

A more effective and also faster method of curing thick rubber items which provide better mechanical properties has been developed by the U.S. Army Materiel Development and Readiness Command at Rock Island Arsenal. The use of microwaves to preheat rubber compounds has brought excellent results in this in-house project. It reflects once again the value of high quality developmental work being done at Army laboratories.

The index listings at the end of this issue complete the update of references started in the preceding issue of the U.S. Army ManTech Journal. This will enable researchers and librarians around the world to reference articles and brief status reports from past issues and should ease their task of determining past developments in the U.S. Army's manufacturing technology program.

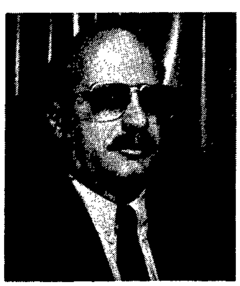
DARCOM Manufacturing Methods and Technology Community



Investment Plan Developed

Project REARM On Track

STEPHEN R. A. ROBINSON is Chief, Project REARM, Rock Island Arsenal, having received this assignment in 1981. He joined HQ, ARRCOM, in 1979 after working as an engineer in the aerospace industry. He is a Registered Professional Engineer in both Illinois and Iowa and has served as an engineering instructor in the Industrial Engineering Institute, St. Ambrose College. He received his M.S. in Mechanics and Hydraulics in 1969 after obtaining his B.S. in Mechanical Engineering in 1963 and a B.A. in Mathematics in 1965.



NOTE: This manufacturing technology project that is being conducted by Rock Island Arsenal is being funded by the U.S. Army Armament Materiel Readiness Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The Arsenal Point of Contact for more information is Stephen R. A. Robinson, (309) 794-5138.

Work is progressing right on schedule for Project REARM (Renovation of Armament Manufacturing) at the U.S. Army's Rock Island Arsenal, Illinois. Project REARM, initiated at Watervliet Arsenal in 1979 and extended to Rock Island Arsenal in 1982, will improve and balance the peacetime production and surge/mobilization capacities of the two arsenals. The Army plans to invest $233 million at Rock Island Arsenal in plant construction, renovation, and new equipment through 1987. (See front cover.) Mobilization leadtime will be cut from 22 to 6 months, and production floor space will be down from 1,900,000 square feet to 1,600,000 with no net increase in personnel.

Mission Multifaceted

The Arsenal's mission is to produce gun mounts, recoil mechanisms, towed artillery, gun carriages, machine guns and other small arms, and related spare parts. (See Figures 1 and 2.) To accomplish this mission, the Arsenal operates manufacturing equipment that ranges from simple engine lathes to complex numerically controlled machining centers (Figure 3.)The Arsenal is unique in a wide range of processes which include casting, metal cutting, closed die forging, heat treating and welding, surface finishing, and the final assembly and testing of complex parts.

First Coordinated Plan Ever

REARM is a program to totally renovate manufacturing operations, including material handling and control, plant maintenance, quality assurance, and the work environment itself. The modernization of Rock Island Arsenal will ensure its ability to produce military hardware in an emergency while private industry converts its production to meet military requirements.

A planned multimillion dollar construction program will include two new manufacturing buildings and the rearrangement of manufacturing operations. Construction will cover a three year period and be phased to prevent interruption of production.

A coordinated program in equipment replacement and rehabilitation will be pursued during the next six years. Project REARM will consolidate manufacturing floor space and will increase efficiency, thus reducing manufacturing lead time. The improved readiness capability will enable the rapid attainment of wartime production levels and put the Rock Island Arsenal back in the lead of armament manufacturing.

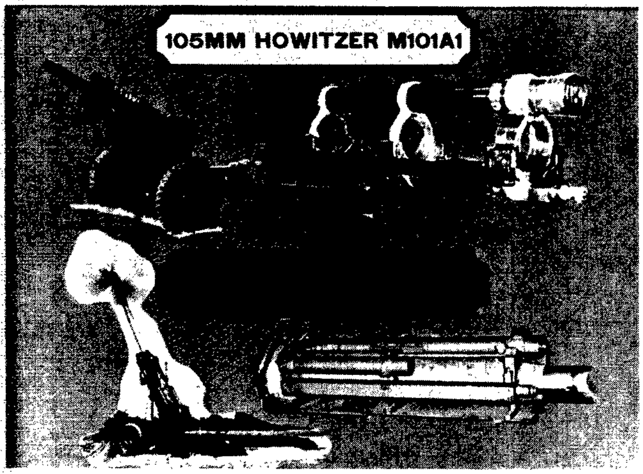


Figure 1

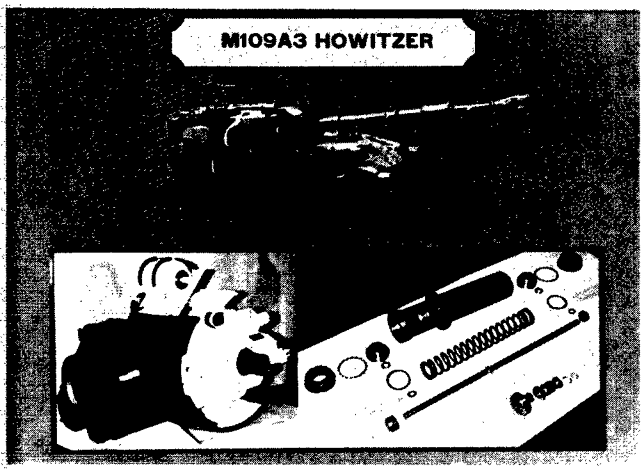


Figure 2

A Total Production Support Facility

But Rock Island Arsenal provides much more than the mechanics of production. Manufacturing arsenals are an essential part of industrial preparedness planning, and Rock Island Arsenal provides

- A large caliber prototype shop offering "drawing board to fabriction"capability for complex recoil mechanisms and gun mounts.
- A focal point for weapons manufacturing methods and technology projects geared to enhance the producibility of gun mounts and recoil mechanisms.
- In-house manufacturing proveout of technical data packages prior to initiation of large scale production.
- A reserve of manufacturing skills and technology to assist industry during initial phases of peacetime or mobilization production.
- Quick response to urgent requirements when industry is unable to respond.
- Low rate production quantities with close tolerance, high skill requirements—batch quantities that private industry considers uneconomical to produce.

Monumental Product Mix Normal

Rock Island Arsenal is a one-of-a-kind job shop. Metal cutting equipment ranges from simple engine lathes to complex five-axis, numerically controlled machining centers (Figure 4). The Arsenal has the only general purpose foundry in the Army capable of producing either cast iron, cast steel (including armor plate), or nonferrous cast products. The Arsenal has a forge shop and can heat treat, weld, and surface finish the products. Finally, it can perform integration and assembly, also acceptance test firing of the end items (Figure 5). It should be noted that job shop foundries, plating shops, forge shops, etc., are available in private industry, but only as separate specialized operations—not collected into a single facility like at the Arsenal.

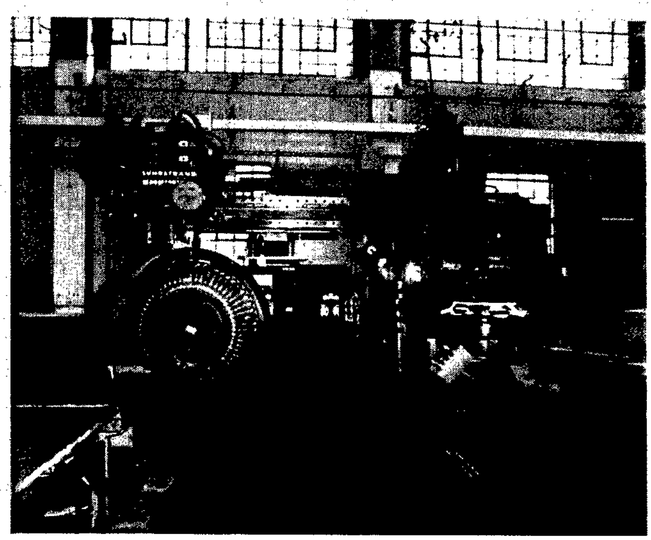


Figure 3

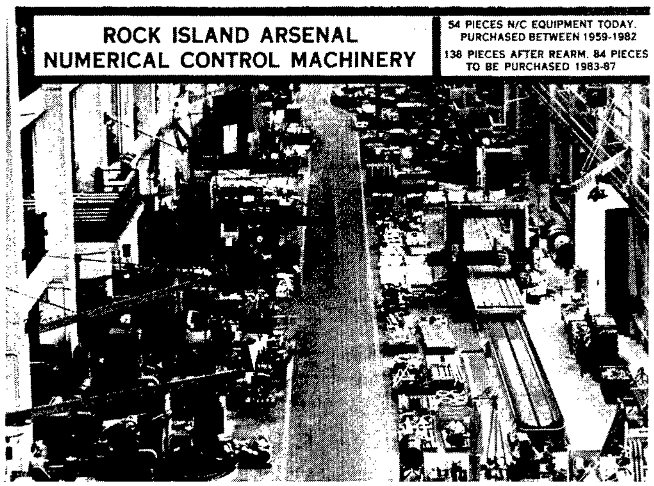


Figure 4

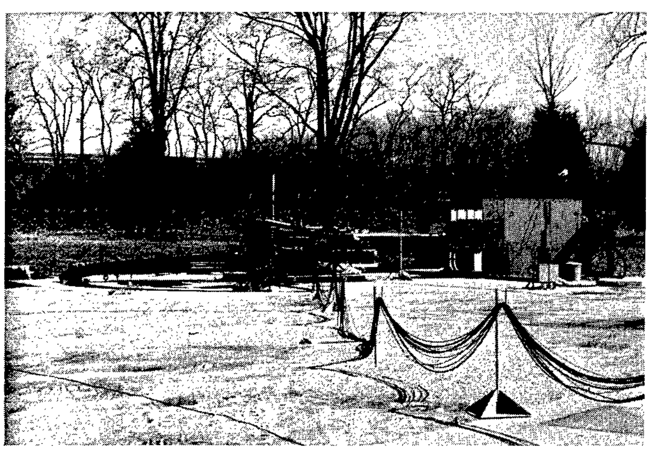


Figure 5

Rock Island Arsenal

Rock Island Arsenal offers complete production capabilities for the execution of small quantity orders quickly and economically. The availability of specialized skills (in a diversified yet complete industrial operation) that can provide quick reaction to a monumental product mix is the basis for its claim to being a unique production facility.

Short Term Solutions of Past

Competition for available funding within the Army over the past several decades has resulted in the decline of the industrial base. This has been especially true at the Army owned and operated arsenals. Rock Island Arsenal currently is performing its mission with old and obsolete equipment and buildings (Figure 6) which are themselves very inefficiently arranged. This has resulted in a shortfall in required productivity and—more seriously—a substantial potential delay in achieving mobilization capacity.

The short term solution to the peacetime production shortfall previously has been to go to two shifts and overtime, stretch out production schedules, and to transfer workload to other facilities, all at higher costs. The necessary long term solution is an extensive capital investment program in the production facilities at Rock Island.

Plant Equipment, Work Flow Archaic

Most of the Arsenal's current inventory of industrial plant equipment was acquired during World War II and the Korean War. Almost 75 percent of this equipment is 20 years old or older. By comparison, only 30 percent of the metalworking equipment owned by American private industry is that old. Figure 7 indicates the relationship of industrial plant equipment acquisition to worldwide conflict.

Plant layout and related work flow also has suffered from the wide separation of facilities that occurred as a result of cyclic building surges coinciding with the Spanish-American War, World Wars I and II, and the Korean War. The movement required for a typical part is shown in Figure 8. The wide dispersion of buildings

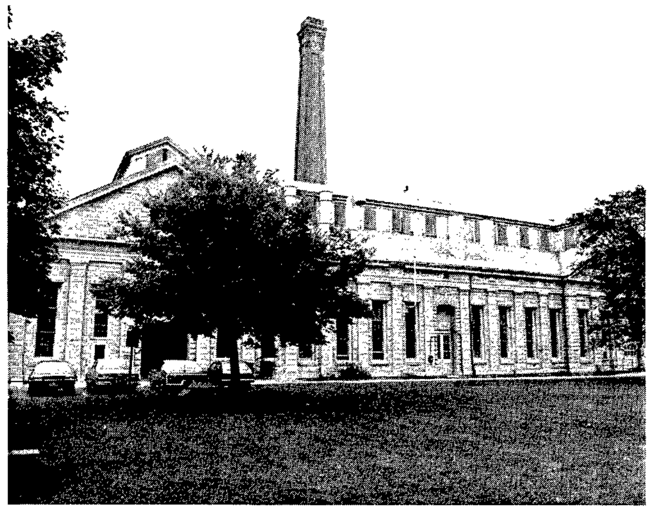


Figure 6

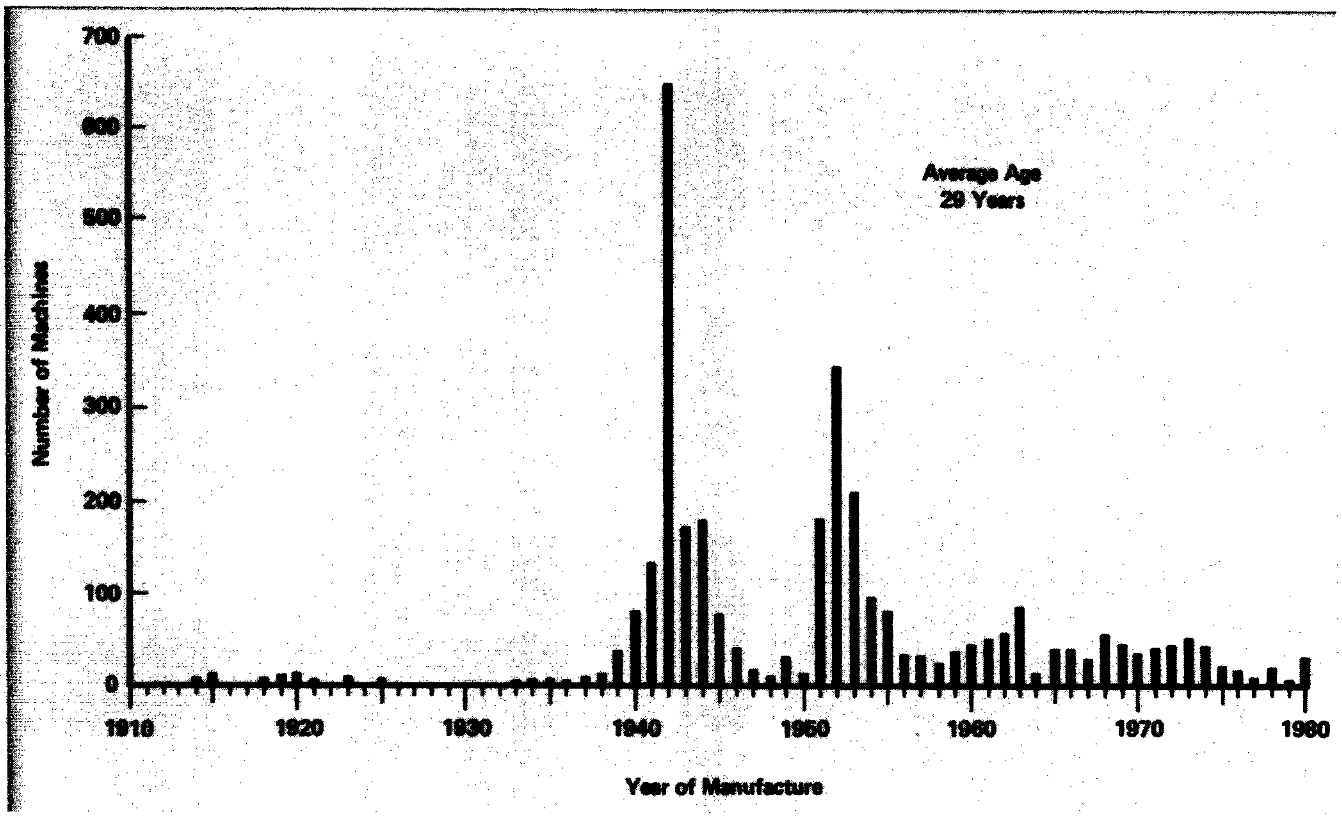


Figure 7

causes increased production time, increased production cost, and wasted energy.

Note that there is eight tenths of a mile between the extreme buildings. The part movement shown covers over three miles in inter-building moves. The work has to be stored or be moved in the open, using the main boulevard of the island. Care must be taken to protect the work from the elements, such as rain, snow, and the salt on the streets. Also, the 8,500 people who work on the island also use this boulevard, conflicting with the flow of work.

History Dictates Change

Some of the specific problems with buildings and equipment are characterized by historical perspective. When the stone shops were constructed right after the Civil War, the items manufactured were small and so were the machine tools. The trend today is for larger machine tools. These buildings have interior columns spaced 30 feet apart, making it difficult to utilize the building for modern manufacturing.

The floor loading capacity of these multistory buildings is inadequate for large machine tools. When equipment of significant size is installed, special supports (Figure 9) must be placed under a floor to carry the increased load; since these buildings are all over 100 years old, their structural stability for modern machine tools is questionable. However, there will be no problem when they are utilized for administrative offices.

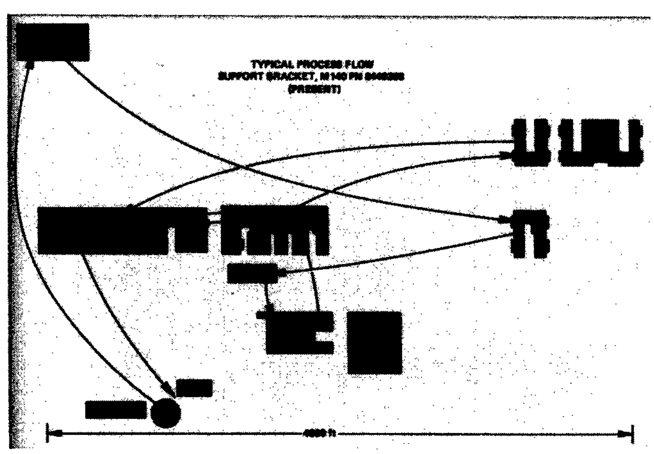


Figure 8

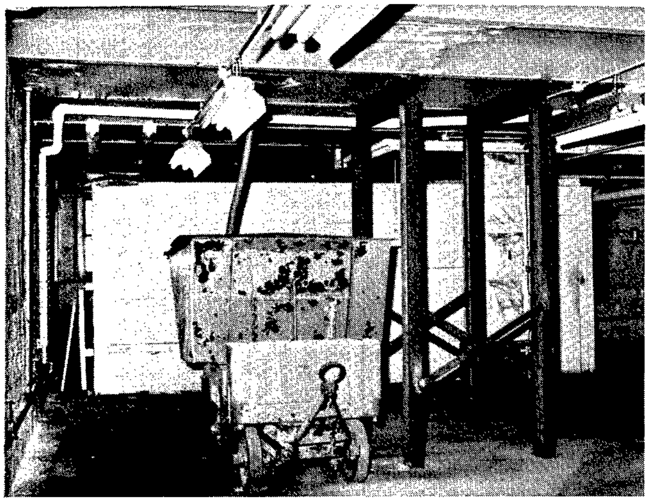


Figure 9

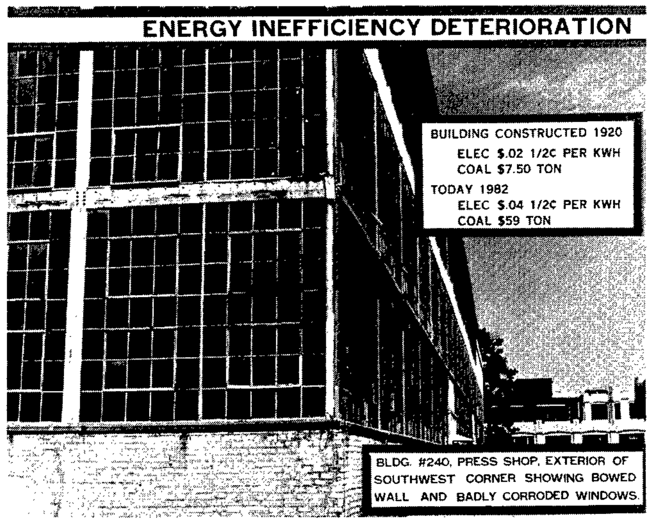


Figure 10

There also is extreme heat loss due to lack of insulation and inefficient window walls in some of the buildings. Figure 10 shows a building that was energy efficient when it was built, since in those days, light was expensive but heat was cheap. The situation now is reversed.

Long Term Fix Only Solution

The problems can be remedied only by consolidation and modernization of facilities, in conjunction with relocation of some equipment.

The Architect's model (front cover) shows the new buildings that will be constructed under REARM. The

EQUIPMENT ACQUISITION —MOD ($143 M)	MILITARY CONSTRUCTION —MCA ($92 M)
1982 STACKER CRANE DESIGN PLANT REARRANGEMENT/SYSTEM SAFETY PROGRAM PLAN	
1983 PURCHASE AND INSTALL INDUSTRIAL PLANT EQUIPMENT (IPE)	(ELECTRICAL UPGRADE OF BLDG 208)
1984 PURCHASE AND INSTALL STACKER CRANE PURCHASE AND INSTALL IPE RELOCATE DEPARTMENTS AND EQUIPMENT	REARM PART I
1985 RELOCATE, PURCHASE AND INSTALL PLATING IPE RELOCATE, PURCHASE AND INSTALL FOUNDRY IPE RELOCATE, PURCHASE AND INSTALL WELDING AND FABRICATION IPE RELOCATE DEPARTMENTS AND EQUIPMENT	REARM PART II
1986 RELOCATE, PURCHASE AND INSTALL FORGE AND HEAT TREAT IPE PURCHASE AND INSTALL IPE	REARM PART III
1987 PURCHASE AND INSTALL IPE SYSTEM PROVEOUT	

Figure 11

portion with the red roof will be a fiscal year 1984 project to house the new NC machining department and high rise automated storage system. The portion with the yellow roof will be a fiscal year 1985 project to house the new foundry, welding, and plating shops.

In fiscal year 1986, an addition will be made to the forge shop (blue roof), plus extensive renovation of existing buildings which will remain in active service. Note that these buildings will be interconnected under one large roof.

Equipping, Construction In Sync

Figure 11 points up the coordination between the equipment acquisition (MOD) and construction (MCA) projects. The program has been "modularized" so that the equipment to go into a new building is scheduled for acquisition in the same or a prior fiscal year as the building. This will allow each phase to come on line as a complete and usable facility. The Arsenal will not have to wait until the entire project is completed before any benefits can be enjoyed. (Note that the electrical upgrade of Building 208 has been included for reference. This had been planned prior to REARM via separate funding as a necessary preliminary step.)

Alternative Courses Considered

Four options to correct the peacetime and mobilization deficiencies were evaluated and compared:

- The status quo option proposed doing nothing and allowing the Arsenal to continue to deteriorate. The Arsenal's mission would be performed by extensive outside contracting. (Unacceptable alternative)

- The conventional option proposed the adding of more people (multiple shifts), with limited contracting. (Currently necessary, too costly for long term)
- The A. T. Kearney, Inc. study was a different modernization plan from REARM. It proposed no new construction, but entailed a much more extensive equipment acquisition program.

- The REARM Plan as described here clearly offered the least cost, most effective alternative.

The economic analysis which supports the REARM Plan has been validated by HQ, ARRCOM, and approved by HQ, DARCOM.

	'82	'83	'84	'85	'86	'87	Total
Military Construction (MCA), $	—	—	22,000,000	[illegible]	23,823,000	—	91,029,000
Equipment Modernization (MOD), $	4,014,000	[illegible]	27,017,000	24,848,000	45,276,000	31,587,000	142,062,000
Total	4,014,000	[illegible]	49,017,000	69,854,000	69,099,000	31,587,000	233,081,000

Figure 12

Funding to Cover Six Years

Funding milestones for Rock Island Arsenal's modernization plan (adjusted for program year dollar values) cover a six year span from FY 82 through FY 87. (See Figure 12.) These milestones include:

- $91,029,000 for construction of two new buildings, an addition to a third, and renovation of buildings to be retained.

- $142,052,000 for modernization, covering both plan rearrangement and the acquisition of new equipment.

At this time, the FY 82 and FY 83 MOD Projects have been approved by the Congress.

Ultimate Facility to Fulfill Mission

Figure 13 shows the current arrangement of the facilities at Rock Island Arsenal. Note that there is about one mile separating the Civil War era stone shops to the upper right (which are considered to be of significant historical value) and the World War I and II production facilities to the lower left. Figure 13 (bottom) shows how the new facilities from Project REARM will be located at Rock Island Arsenal. Note how the new construction of 300,000 square feet will conform to and augment existing facilities. It must be reemphasized that REARM will be executed so that production at the Arsenal will not be interrupted and that each construction phase will provide a complete and immediately usable facility.

In summary, Project REARM will

- Enable Rock Island Arsenal to increase its peacetime single shift productivity from 1,200,000 to 1,700,000 direct labor hours per year

- Reduce its mobilization leadtime from 22 to 6 months

- Reduce its active production floor space from 1,900,000 to 1,600,000 square feet with no net increase in personnel.

The Rock Island Arsenal has a significant role yet to play in the nation's defenses, and Project REARM will give the Arsenal the capabilities to do that job.

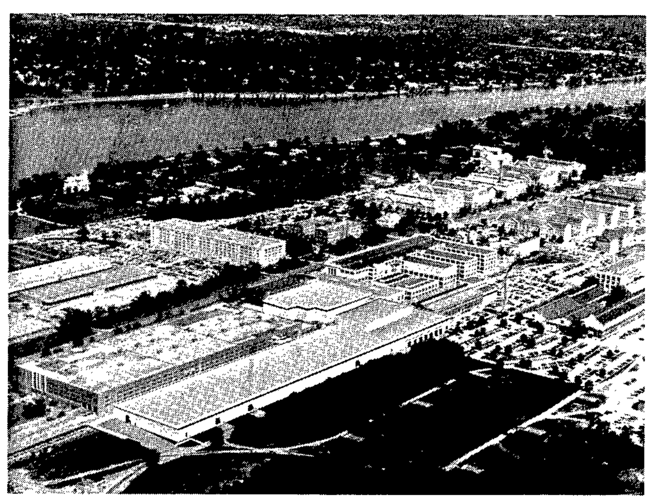


Figure 13

THE ISLAND OF HISTORICAL TREASURES

Rock Island Arsenal, established in 1862, has become one of the largest in the United States Government. With the Army reorganization of 1962, it has also become the Headquarters of the U.S. Army Armament Materiel Readiness Command. The Island itself is approximately three miles long and 3/4 mile wide at its widest part.

The government, represented by William Henry Harrison, acquired the Island from the Indians by a treaty at St. Louis in 1804. This treaty was never recognized by Chief Black Hawk and eventually led to the Black Hawk War of 1832.

During the war with Spain, the Arsenal fabricated most of the articles of equipment for the infantry, cavalry and artillery soldier. The limber and caisson, battery wagon and forge for the 3.2-inch field gun, 7-inch howitzer and 5-inch siege gun were manufactured here. The Arsenal also functioned as a large storage and issue depot. The number of employees increased from 500 to 2,900 during this period.

During World War I, approximately $90,000,000 was spent in the manufacture of gun carriages, limbers, battery and store wagons, recoil mechanisms, rifles and numerous other items. The number of employees rose from 3,000 to 13,400.

In World War II about $200,000,000 was spent in the manufacture of recoil mechanisms, gun carriages, machine guns and mounts, airplane gun mounts, ship mounts, hand carts, etc. Employment increased from 2,734 in 1939 to 18,467 in 1943.

The principal activities of the Arsenal during the Korean conflict were development and manufacture of the Bazooka and the 4.2-inch mortar and overhaul and rehabilitation of tanks, artillery and small arms. Employment rose from 3,498 in 1950 to 6,968 in 1952.

Today, employing over 3,000, Rock Island Arsenal is responsible for the production of carriages, recoil mechanisms for towed and self-propelled artillery, and for tank armament. The installation also provides administrative, logistical, and facilities support services to Headquarters, U. S. Army Armament Materiel Readiness Command (ARRCOM), and other tenant agencies. With the inclusion of Headquarters, ARRCOM and tenants, the total Island employs approximately 8,500 people.

Site of Fort Armstrong (1816-1845)

The Island was first occupied by the military in 1816. A permanent fort was completed in 1817 and named Fort Armstrong after the then Secretary of War.

It became the focus of the Black Hawk War in 1832 when, in the spring of that year, the Illinois Volunteers and United States regiments gathered here before pursuing Chief Black Hawk up the Rock River. Many men on this expedition rose to fame in later years. Among them were Major Zachary Taylor, Abraham Lincoln, And Jefferson Davis.

Lincoln Decision Far Reaching

A bridge monument made of stone from an original bridge pier in the first bridge to span the Mississippi was completed early in 1856.

Damaged badly by the steamboat Effie Afton within a month of its opening, it was repaired and in service until the winter of 1872 when replaced by the first Government bridge located on the same site of the present bridge to Davenport, which was built in 1895. The disaster of the Effie Afton caused the river interests to bring suit against the bridge company, who won the suit, represented by lawyer Abraham Lincoln. The resulting decision set a precedent that no interest could stop the construction of bridges across a navigable stream. This advanced the settling of the West many years.

Confederate Prison Site

The Confederate prison was established in 1863. First prisoners were Southern troops captured in the Battle of Lookout Mountain and Missionary Ridge by General Grant's Army, November 26-27. Five thousand five hundred and ninety-two prisoners were received on December 3, 1863. The prison doctors found 94 cases of smallpox in its most virulent form. Active as a prison for 20 months, there were 12,215 prisoners confined during this period; the most confined at any one period was a little over 8,000. There were 41 successful escapes. Some died while confined, principally from smallpox. The last prisoner was discharged from the prison hospital in July 1865.

Confederate Cemetery

Originally containing the bodies of 1,961 prisoners who died while confined here during the Civil War, 11 bodies have since been removed to their home state, one as recently as 1955. Each Memorial Day, Confederate flags are placed before every headstone, a firing detail fires three volleys, and a bugler sounds taps.

National Cemetery

This cemetery was established in 1865 as a post cemetery. Today, approximately 11,000 veteran dead of our country's several military services are buried here. The Union dead from the units stationed on the Island as prison guards lie in the southeast corner of the cemetery. These are all reinterments from their original burial ground. Unfortunately, their original burials were marked only with names painted on rough boards. Weather and vandalism obliterated many, with the result that in this corner headstones marked "Unknown" are found many times.

General Rodman's Grave

General Thomas J. Rodman, called the Father of Rock Island Arsenal, died while commanding in 1871. At the express wishes of the then Secretary of War, his body was laid to rest here. The cannon at his grave site are appropriate in that they were cast by his revolutionary process, a process so important at the time it changed the world's views on casting cannon.

Arsenal Museum

Rock Island Arsenal Museum, established in July 1905, contains one of the largest military arms collections in the Mississippi valley.

It was rededicated in 1959 as the John M. Browning Memorial Museum, as a memorial to the father of automatic weapons for his contributions to the military services of his country. These contributions included the U. S. Automatic Pistol, Model 1911 (Colt); the Browning U. S. Machine Gun, Model 1917; and the B.A.R., U. S. Automatic Rifle, Model 1918.

Weapons that may be seen in the museum date from the pre-Revolutionary War period to the present including many weapons captured from hostile Indians, the enemy in the Civil, Spanish-American, World Wars I and II, and the Boxer Rebellion.

Brief Status Reports

Project 1075. Electronics Computer Aided Manufacturing (ECAM). Although integrated circuits, hybrid circuits, printed circuits, and cables are designed on a computer, there is little computerized control of processes used to produce these items. A master plan is needed to define the area and requirements. This project will develop a DOD master plan for computer-aided design and manufacturing of electronic systems. The Air Force's ICAM and NASA's IPAD programs will be used to define CAD/CAM and electronic technologies to make integrated circuits, hybrid circuits, printed circuits, and cables. Technical requirements and evaluation criteria were reviewed by CAD-CAM electronics working group. Comments were incorporated. A contract services review board is checking the package. The contractor will develop architecture for ECAM using ICAM definition. For additional information, contact G. Little, MICOM, (205) 876-3604.

Project 1086. Cobalt Requirement in Maraging Steel for Rocket Motor Components. Current high performance rocket motor components utilize maraging steels in large quantities. Cobalt, one of the key ingredients, comes from politically sensitive areas and could be difficult to obtain. This project will optimize mill procedures and evaluate in a rocket motor the new cobalt-free maraging steel alloys. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 1088. Optimized Mandrel Fabrication and Utilization for Component Motor Cases. Optimizing production procedures to obtain lowest unit cost while maintaining reliability in fabrication, this project will establish production procedures and production rates for mandrel fabrication. This will provide production engineering data essential to current and future motor component requirements. For additional information, contact B. Austin, MICOM, (205) 876-2147.

Project 7710. Injection Molding of Rubber Obturator Pads. The high cost of the standard neoprene rubber obturator pad for 155 mm cannon is due largely to the long two-hour cure required in the compression molding operation. This project will establish injection molding process which will permit the fabrication of an obturator pad in about ten minutes. Different injection time/temp cycles were studied to determine optimum molding cycle parameters. The neoprene compound has been successfully injection molded. Quality assurance testing of injection molded obturator pads revealed dimensional deficiency in the area of the four mold vents. Dimensions in the gate areas were excellent. Work will be extended to resolve the dimensional problem. For additional information, contact F. Testroet, ARRCOM, (309) 794-6098.

Project 7724. Group Technology of Weapon Systems. There is a need to reduce and control the proliferation of parts and designs for items manufactured at Watervliet Arsenal. The Army has purchased a group classification and coding software package. Once this system is implemented, it should be possible to reduce the number of different parts thru standardization. Drawings and routings have been coded. Files have been established based on quantities manufactured and purchased. A machine tool file has been established. Analysis programs are being run to identify machining modules. Using MICLASS, a total of 474 rotational parts have been coded. The feasibility of establishing a manufacturing cell was not verified. Future work will be directed toward automated process planning. For additional information, contact D. Dunlap, ARRCOM, (309)794-3270.

Project 7714. Multi-Mode Weapon and Mount Impedance Simulator (CAM). Present test methods do not compensate for various measures and for multiple modes of vibration of weapon mounts. This project will build a simulator capable of variable weapon-mount impedance and of several excitable modes of vibration. This project will result in test equipment to support all small and medium caliber weapons and ammunition. The test equipment (simulator) has been completely assembled and is undergoing tuning of the main servo valve. For additional information, contact R. Radkiewicz, ARRCOM, (309) 794-6868.

Project 6774. Manufacturing Methods for APDS Projectile. Mass production methods for the fabrication of major projectile components, particularly sabot, present process variables which are difficult to control to obtain consistent quality. This project will develop techniques for injection molding the plastic components around the penetrator, also develop automated mechanisms to demonstrate maximum manufacturing rates. The four-cavity molding machine has been completed and installed at Ford. The trim station was completed and is also installed. About 512 projectiles were assembled and test fired. Performance was acceptable. For additional information, contact J. McCormick, ARRADCOM, (201)724-4713, or J. Borri, MPBMA, (201)724-4081.

Project 1296. Manufacturing Technology of CB Filters. Existing filter production facilities are obsolete, inefficient, and expensive to operate. This project will modernize and consolidate all areas into one facility design. New process equipment. SP1 evaluated charcoal handling equipment. SP2 developed perforated plate and screen dispersion machine. Investigated vibration to compact charcoal and prepared technical report. For additional information, contact G. Dickey, ARRCOM, (309) 794-4351, or D. Dunlap, (309) 794-3270.

Project 1318. Chemical Production Fill, Close, and LAP for 8 Inch XM736 Projectile. The QL process for VX binary manufacturing results in large quantities of waste and organic phosphorus compounds. Prior procedures for disposal (deep well) are no longer acceptable. New techniques are required. This project will establish processes to reduce waste by-products and provide methods for disposal of unavoidable waste material from process manufacturing. Alternative process evaluation of potential QL waste treatment methods was completed. Pre-pilot scale testing of potential processes was initiated. Emphasis was on recycle of usable wastes to reduce total QL waste streams. For additional information, contact C. Heyman, ARRCOM, (309) 794-4286, or D. Dunlap, (309) 794-3270.

Project 7920. Conservation of Critical Materials for Gun Tubes. Gun steel requires an alloy such as chromium, which is becoming scarcer and which must be obtained from out of the country and from relatively few nations. There is a need for materials and processes which use less of a critical element such as chromium. Alloy steel variations which replace chromium with boron and molybdenum have been developed but have processing problems. This project will generate process modifications to allow use of steels with less critical alloys. A set of six small heats with varying amounts of molybdenum and chromium have been forged. Tensile and Charpy coupons have been sectioned and heat treated. Mechanical property tests will be conducted shortly. For additional information, contact S. Tauscher, ARRCOM, (309) 794-5517, or D. Dunlap, (309) 794-3270.

Project 4506. 5.56 mm Cartridge Linking System. There are currently no linking machines available for linking production quantities of 5.56 mm ammunition. The manual and semimanual methods available are slow and costly. Linking machines for 7.62 mm ammunition exist; a modification and improvement should provide a satisfactory solution. A production rate of 65.8 million rounds per year is required. For additional information, contact W. Phillippi, ARRADCOM, (201) 724-3580, or B. Hazduczok, MPBMA, (201) 724-2742.

Project 4553. Process Parameters for Cold Drawing Alloy Steels. The use of more highly alloyed steels to meet property requirements may negate use of the cold draw process, with resultant cost increases. This project will develop the necessary processing parameters to enable continued use of the cold draw process on high performance steels. For additional information, contact D. Gustad, ARRADCOM, (201) 724-2522, or R. Perciballi, MPBMA, (201) 724-4086.

Project 4555. Infrared Monitoring of Pyrotechnic Blending. During blending operations in the manufacture of numerous pyrotechnic compositions, flashes or fires in the blender and bays are a persistent problem. A warning system will be developed to detect a flash or fire, warn personnel, and quench the mix before combustion takes place. For additional information, contact J. Matura, ARRADCOM, (201) 724-6104, or S. Nemiroff, MPBMA, (201) 724-2786.

Project 6200. Small Caliber Ammo Process Improvement Program. The existing batch process (over 30 years old) consists of manual material transport, limited production rates, and outmoded inspection systems. This project will use an integrated, continuous process production system from raw materials to packed-out ammunition. The cupping press and additional tooling are being packed for shipment to Olin Corporation. A Bliss No. 6 press has been installed. There will be a 90-day production run. For additional information, contact M. Lena, ARRADCOM, (201) 724-5688, or B. Hazduczok, MPBMA, (201) 724-2742.

Project 6472. Alternate Processes for Fabrication of Precision Parts for MT Fuzes. Precision fuze pinion fabrication is dependent mainly on foreign sources. This project will investigate alternate fabrication processes including die casting, chemical etch/diffusion bonding, powdered metallurgy, and molded plastic. Process parameters and die design to provide acceptable product were established. Additional dies were fabricated and testing was initiated to evaluate the process

for other pinion configurations. For additional information, contact D. Reap, ARRADCOM, (201) 724-5097, or D. Carrigan, MPBMA, (201) 724-4081.

Project 6596. Ball Propellant Pilot Plant Studies. A pilot facility with variable control systems is needed. Current engineering work must be performed on production lines when available. This conflicts with productive operations. This project will construct a pilot facility with full instrumentation and variable process control systems for monitoring all critical phases and permitting rapid experimental changes. In the ten gallon still, heavy wall coatings of lacquer films found at 120% of normal loading. Reduction in loading to 110% appears to eliminate dead spots. The maximum yield studies in the 100 gallon still were more disrupted by rafting than in the 10 gallon still. For additional information, contact R. Pizzola, ARRADCOM, (201) 724-2693, or T. Gropler, MPBMA, (201) 724-2841.

Project 6599. Second Generation Electro-Optic Projectile Cavity Insert EQ for 155-175 mm Projectiles. Inspection of the quality of the inside surface of 155 and 175 mm projectiles through the fuze hole is difficult, slow, and not always accurate. A prototype electro-optical TV inspection system was developed and is being evaluated. A ruggedized model will be designed and a prototype built. Twenty-four M107, 155 mm projectile bodies with internal defects for use as standards have been received by ARRADCOM. Eight bodies with no defects also have been shipped to the contractor. The contractor has installed the equipment at his new facility and is proceeding with the design phase of the contract modification. For additional information, contact H. Wolter, ARRADCOM, (201) 724-3877, or Y. Wong, MPBMA, (201)724-4084.

Project 8165. Standards for Diamond Turned Optical Parts. Existing surface finish standards and testing equipment and techniques do not cover the range of diamond turned optical surfaces for a production environment (½ to 1 microinch). This project will correlate laser scatterometry and interference contrast microscopy with functional optical testing to optimize the specification of the surface with a measurement technique for a production environment. A draft scope of work has been prepared for this project. For additional information, contact J. Argento, ARRADCOM, (201) 724-4238.

Project 7726. Application of Cold and Warm Forging. Processing parameters for warm and cold forging are not available. This project will process warm and cold forging through the rotary forge. An electronic malfunction prevented cold forging trials. Battelle - Columbus Laboratories' proposal on a computer program for simulation of the rotary forge line has been accepted. For additional information, contact L. Liuzzi, ARRCOM, (309) 794-5827, or D. Dunlap, (309) 794-3270.

Project 0900. Automated Multiple Filter Life Tester. There is a low test rate capacity and an increasing volume of testing for the current filter life test equipment. This project will reduce manpower needs by developing a multiple test chamber tester which will permit four items to be tested simultaneously. Due to past difficulties, it has been decided to perform the work in-house, with supplemental subcontracts where technology consultation is required. Two flow schemes have been completed and are mutually compatible. One unit can use either agent. For additional information, contact G. Lattin, ARRADCOM (CSL), (301) 671-3510.

Project 1005. Ceramic-Metal Substrates for Hybrid Electronics. All thick film hybrids are fabricated on a ceramic substrate which is fragile at high G shock levels and must be adequately supported in order to survive. This is a costly procedure. This project will develop manufacturing methods and techniques for production of thick film hybrid circuitry on metal-based substrates. This includes processes for an insulating layer on a metal substrate and processing of thick film materials to form electronic components. Westinghouse is setting up production process, rates, and equipment for making thick film hybrid fuze circuits on porcelain enameled steel substrates. Resistor material investigation is under way. For additional information, contact A. Lee, ARRCOM, (309) 794-2840, or D. Dunlap, (309) 794-3270.

Project 1001. Pilot Line for Fuze Fluidic Power Supplies. Fluidic generators are complex and costly to produce. In production, close tolerances and small part assembly are reflected in high cost and low yield. This project will identify and adopt the most economical manufacturing processes and techniques to establish a mechanized pilot line for assembly of fluidic power supplies. For additional information, contact H. Lee, ARRCOM, (309) 794-3193, or D. Dunlap, (309) 794-3270.

Project 3204. Internal Shear Forging for Missile Primary Structure. Each section of the primary structure of the Pershing missile contains intermediate stiffening rings and splice rings on each end. The splice rings are machined to dimensions required for welding and then finish machined. This project will develop an internal shear forging technique that produces the rings and skins of the primary structure as one integral part. The basic design concept did not support the loads generated. The concept was drastically revised with good results. Internal shear forging preforms to finish dimension is now proceeding. For additional information, contact J. Honeycutt, MICOM, (205) 876-1074.

Project 3218. Reduce Finishing Cost of Slip Cast Fused Silica Radomes. Radome manufacturing costs are high and yield is low. This project will investigate various approaches to matched casting. Four additional radomes (15 total) were cast. Two were damaged by the loss in internal seals during casting. The sealing system was upgraded. Two castings were made satisfactorily. Problems during sintering suggested improvements to kiln controls. Correlation between castings and mandrel dimensions was completed. Mandrel modification parameters were developed and the mandrel is being modified. A meeting with Raytheon was held to facilitate future technology transfer. For additional information, contact P. Ormsby, MICOM, (205) 876-4933.

Project 6760. Drying Low Density Ball Propellant. Low density ball propellant is low in weight, high in moisture content, and more hazardous than conventional ball propellant, thus creating a number of problems in drying process. This project will evaluate other techniques for drying low density ball propellant such as rapid frequency energy and superheated steam drying. Fluid bed drying system fabrication and acceptance testing completed. System received and installation completed. Calibration efforts completed and drying tests for design of batch production scale dryer completed. Experimental testing has been completed and conditions for continuous operation and control have been defined. The final technical report is being prepared. For additional information, contact J. Goldman, ARRADCOM, (201) 724-5043, or T. Gropler, MPBMA, (201) 724-2841.

Project 3219. Automatic Polymer Attachment Production Methods. Present technology employs a polymer dispensing machine which is operated manually—a time consuming and costly process. This project is to develop an automatic production polymer attachment method that will dispense the exact amount of polymer onto a substrate, pick the chip from EHT wafer pack, and orient the chip before placing it onto the polymer. For additional information, contact B. Austin, MICOM, (205) 876-2147.

Project 3280. Engineering Analysis of Manufacturing Parameters for Thermal Batteries. Slight variations in manufacturing parameters have a greatly magnified effect on final battery performance and, as a result, rejection rates are high. This project is to optimize each facet of manufacturing techniques by statistically correlating varied parameters. Scope of work being revised and ready for issue. Basically consultant TBN will review thermal battery problems in all services and recommend next step. For additional information, contact P. Wanko, MICOM, (205) 876-7097.

Project 7807. Programmed Optical Surfacing Equipment and Methodology - CAM. Current techniques for pitch buttoning and blocking precision lenses use older, conventional equipment. Accuracy depends on the skill and experience of well trained master opticians who are becoming scarce. This project will adopt computer techniques and instrumentation with controls to pitch buttoning and blocking operations. The end product will be an integrated surfacing system implemented in the fire control fabrication facility at ARRADCOM. A contract was awarded to the University of Rochester for a CNC Optical Surfacing Center. A Bostomatic 1312 CNC machining center was purchased and installed at the Institute of Optics, University of Rochester, for subsequent modification, instrumentation, and testing. For additional information, contact N. Scott, ARRADCOM, (201) 724-6945.

Project 7644. Application of Integral Color Anodizer for Aluminum. The necessary coloring of anodized aluminum for camouflage requires extra process steps. This project will provide parameters for a process that imparts color to coating during the anodizing process. ICA-treated coupons with superior coatings with respect to abrasion resistance, coating uniformity, and light fastness were further evaluated for their heat resistance. Laboratory evaluations have been completed. The superiority of the hard coating process was demonstrated. Thirty M1GA1 receivers coated with charcoal gray ICA coating were provided to the infantry board for field evaluation. For additional information, contact W. Ebihara, ARRADCOM, (201)724-3505.

Project 6632. Auto Inspection Devices for Artillery Projectiles in Modern Plants. Current methods of manufacturing artillery components utilize considerable amounts of manual operations during in-process and final acceptance inspection. This project will design, fabricate, and test an automated prototype inspection system which provides process control and product assurance for a new, modernized large caliber production line. A flash hole detection system was fabricated. Development of the hot forging inspection device and the billet tester were discontinued. The ogive system was completed and shipped to ARRADCOM. For additional information, contact H. Bolk, ARRADCOM, (201) 724-4982, or Y. Wong, MPBMA, (201) 724-4084.

Project 6640. Production Control/Quality Assurance of Shaped Charge Liner by Auto X-ray Analysis. The current X-ray inspection method is of questionable value for monitoring production or predicting the ballistic performance of shaped charge liners. A computerized X-ray inspection method will be applied which can automatically produce and evaluate detailed grain orientation texture maps of the jet-producing portion of the charge liner. The contract to load, and statistically test fire has been awarded. Seventy percent of the sample projectiles have been static spin tested. X-ray specimens have been fabricated and are being evaluated. Results indicate that liners from cross rolled material produced more consistent penetration than conventional liners. For additional information, contact F. Witt, ARRADCOM, (201) 724-4225, or M. Danesi, MPBMA, (201) 724-3026.

Project 7809. Leak Detection Techniques for Small Sealed Fire Control Assemblies. Leak testing by standard pressure testing methods on small sealed fire control assemblies is difficult, far from precise, and does not provide the desired confidence level. A helium leak rate testing method will be modified and adapted for use with fire control assemblies. A prototype leak detection test fixture was partially completed during FY79. Additional funding to complete fabrication of the test fixture and validate the new process was approved by DARCOM. For additional information, contact T. Gavanis, ARRADCOM, (201) 724-6488.

Project 6738. Ultra-High Speed Metal Removal, Artillery Shell. Due to the low metal removal rates of the current conventional machining operations, a greater number of machines are required to produce artillery projectiles. This project purpose is to achieve increased metal removal rates and also to reduce the number of machines currently used to produce projectiles. Machining studies have been completed on four types of steels using five types of cutting tools. Results show that machining speeds can be significantly increased with the new generation tooling. For additional information, contact R. Pohl, ARRADCOM, (309)794-3050, or G. O'Brien, MPBMA, (309)794-3730.

Project 7201. Artillery Weapon Firing Test Simulator. Soft recoil type weapons accelerate the recoiling parts forward before the propellant is ignited. To test such weapons, the simulator ram must impact the gun tube muzzle when the muzzle has moved forward the proper distance. This project will provide a control system to phase the triggering of the simulator with that of the weapon so impact occurs at the proper point. Installation of a second simulator is complete. Major problems have been resolved. However, minor software/simulator interface problems are delaying completion. Minor software revisions are planned and final training is being scheduled. For additional information, contact D. White, ARRCOM, (309) 794-6745.

Project 3139. Millimeter Radiometric Seekers for Submissile Application. Low quantity production is too costly for the system requirements. This project will provide an alignment and test fixture to speed assembly and test of the gimbal assembly. This will establish a method of molding the steps in the lens. Photolithographic techniques will be used on the xmitter/RCVR structural assembly. Sperry wrote a computer math model to evaluate antenna component materials and sensitivity to radome. Also determined more efficient packaging specs; major components were sent to RF part vendors. Will now work on assembly methods. For additional information, contact A. Green, MICOM, (205) 876-1728.

Project 3142. Production Methods for Low Cost Paper Motor Components. High volume missiles and rockets use high-strength-to-weight metal motor cases which are a costly item. This project will establish winding techniques for turning out low cost paper-phenolic motor case bodies on standard industrial tooling. Full scale motor concept demonstration completed. Reproducibility demonstration with production contractor nearing completion. Delivery of production components for test firing initiated. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 1121. Missile Manufacturing Productivity Improved Program. The Hellfire missile will be built in facilities that are not modern, with processes that are not optimum and with equipment that is not updated. A study of methods, equipment, and facilities is needed with a view toward modernization. This project will develop a plant modernization plan in which government and the companies share in the updating of processes and equipment and also share in the savings obtained. Programs will be conducted at Rockwell-Columbus and Martin-Orlando. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 3115. Engineering for Calibration Equipment. Measurement sciences or metrology must be continually advanced in relevant technology areas to keep pace with many Army programs. Advancements must be made by deriving new types of standards. Data collection for the pilot program (first round) for coaxial bolometric power has been initiated, including a detail analysis. The results of the analysis will serve as a guide for the future. This task is considered complete. For additional information, contact F. Seeley, MICOM, (205) 876-7718.

Project 7580. Pilot Auto Shop Loading and Control System-CAM. A more effective system is required for shop loading and control of production. The system should be more responsive to schedule changes. This project will install a computerized system for control of production scheduling of shop orders. Current-status information will be available through random access. Employ priority sequencing. The inventory/open order module was implemented. Software programming continued on the material requirements and capacity planning module. Efforts on the cost monitoring and control module have been delayed pending implementation of other modules. All major design decisions required to define the remaining material requirements planning, capacity planning, and cost control were finalized. The remaining development work was complete during the reporting period. For additional information, contact S. Macomber, ARRCOM, (309) 794-6133.

Project 7605. Chemically Bonded Sand for Close Tolerance Casting. Present methods of molding and core making are costly, energy wasteful, and unsuitable for holding close tolerances. This project will install a chemically bonded sand core making and molding system at Rock Island Arsenal which will reduce labor cost, eliminate baking cores, and create more rigid molds. The contractual effort to design a mold and core making system has been completed. The core making system has been received and will be installed when material for utilities hookup are received. For additional information, contact R. Kalkan, ARRCOM, (309) 794-6098.

Project 7532. Single Point Cutting for Metal and Plastic Optics. To fabricate a laser surface mirror to precision tolerances without burnishing or crushing the surface, this project will develop single point diamond tool cutting. Planed surfaces turned on 4-inch discs of copper and aluminum with a single point diamond tool had 4 micro-inch finish, not 1 micro-inch. The diamond-turning machine acquired via this project has been installed at a MICOM subcontractor location. Tooling problems have prevented the initiation of experimental operations. For additional information, contact D. Dunlap, ARRCOM, (309)794-3270.

Project 7555. Dynamic Pressurization Slide Block Breech Mechanism. Due to testing costs for proof firing slide block breech mechanisms, this project will design and fabricate a dynamic pressurization test stand to simulate proof firing. Problems with the reliability of the system have delayed the acceptance. The stub tube was completed and is in the process of being inspected. For additional information. contact D. Dunlap, ARRCOM, (309) 794-3270.

Project 1072. Multiple High Reliability/Low Volume LSI Manufacturing. Low volume purchase of LSI chips does not lend itself to circuit variations. Larger than needed numbers of chips must be ordered to get the producer's attention. A low volume chip capability is needed. This project will analyze all LSI research results and single out new processing techniques. It will also establish a military captive design and production line, develop software for DAC of LSI circuits, and produce variations of several circuit families. A contractor will analyze large scale integration (LSI) manufacturing techniques to develop a comprehensive production plan. Computer aided design will be used and work will focus on linear LSI technology. Contractor proposals are being reviewed. For additional information, contact R. Wootten, MICOM, (205) 876-8487.

Project 3436. Ceramic Circuit Boards and Large Area Hybrides. Advanced weapons systems now require greater complexity and packaging density than can be produced by conventional hybrid technology with suitable cost and reliability tradeoffs. This project will develop improved processes and techniques for fabricating reliabile, high density hybrid circuits. For additional information, contact P. Wanko, MICOM, (205) 876-7097.

Project 1109. Robotized Wire Harness Assembly System. Wire harness fabrication is a labor intensive process. Approximately 50% of harness fabrication time is devoted to handling, sorting, and identification. Harness assembly is done by hand. Procedures use several work stations and repeated handling. A computer controlled manipulator (ROBOT) with six degrees of freedom incorporates wire preparation, harness assembly, and testing into a single work station. An integrated systems approach will incorporate state-of-the-art equipment and techniques. For additional information, contact B. Austin, MICOM, (205) 876-2147.
testing. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 3411. Manufacture of Non-Planar Printed Circuit Boards. Use of flat circuit boards results in complex and expensive interconnections with lowered reliability. This project will develop the processes to produce non-planar circuit boards shaped to fit the available compartments. Circuit patterns will be exposed on the inside with a projection mechanism or with soft X-rays. A method of mass soldering will be developed. For additional information, contact R. Brown, MICOM, (205) 876-5321.

Project 1108. RF and Laser Hardening of Missile Domes. Current radomes are susceptible to damage by laser energy and they also permit laser and radio frequency energy to damage the detector. This project will develop RF sputtering methods to apply indium oxide, tin oxide, and another material to the inside of the glass or plastic radome. Coatings that pass only .8 to 1.5 micron wavelengths will be used. For additional information, contact B. Austin, MICOM, (205) 876-2147.

Project 7285. Cast Titanium Impeller for Turbine Engine. Current centrifugal compressor impellers are fabricated by machining the flowpath and blade surfaces from a forging. This results in a substantial loss of material and expensive machining operations. This project will establish the fabrication of titanium compressor impellers by casting and hot isostatic pressing (HIP). This method will reduce fabrication costs by 40 percent. Industrial R&D conducted by gas turbine engine manufacturers has demonstrated feasability. Detroit Diesel Allison has completed the evaluation of titanium castings. Solar Turbines has completed the effort evaluating mold modifications and alternate HIP/chem mill and heat treat procedures using castings from PCC and TiTech. For additional information, contact M. Galvas, AVRADCOM, (314) 263-2771.

Project 3423. Low-Cost/High-Performance Fibrous Graphite Rocket Nozzles. Rocket systems using high-performance carbon/carbon or pyrolytic graphite nozzles incur high component cost. This project will scale up the fibrous graphite process to make full-scale nozzle components and will extend nozzle test data. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 9860. PDN Techqe-Gallium Arsenide Microwave Field Effect Transistors. No production process is available for producing microscopic field effect transistors for use at microwave frequencies. This project will develop processes for defining one-micron line widths two microns apart. Control epitaxial depths to 0.1 micron and diffusion depths to one micron. Hughes Aircraft Co. started the baseline effort. A process manual was begun, a substrate spec written, wafers ordered for ion implantation, a silox deposition system evaluated, and packages surveyed. Hughes built GA-AS field effect transistors on a production line and they had good electrical properties. They are establishing completely automatic, computer controlled manufacturing techniques to repeatedly produce active device layers in semi-insulating gallium arsenide. Ion implantation and photolithography are being used. Hughes established an automated wafer processing line for Gallium Arsenide (GA-AS) field effect transistors (FET). Samples are undergoing in-house testing. For additional information, contact I. Chase, ERADCOM, (201) 544-4833.

Project 6736. Tech Readiness Acceleration Thru Computer Integrated Manufacturing (CAD). The lead time required to bring production lines to mobilization maximum is intolerably excessive. A critical deterrent is the extreme shortage of toolmakers and machinists. The development and implementation of a computer integrated manufacturing system will significantly reduce the requirement for highly skilled craftsmen. The basic computer input requirements were designed and completed for the tooling wedge data base system. This is a final status report for this project. For additional information, contact R. Katz, ARRADCOM, (309)794-6515, or D. Booker, MPBMA, (309) 794-4081.

Project 7317. Optimization of Step Thread Tooling. Much of the tool is lost due to limitations of sharpening. The cutter blades should be evaluated in an attempt to obtain more durable and readily grindable steel. This project will redesign the cutter blade

and/or its holder to provide more resharpening capability. Newer cutting steels offer better formability and can provide capability of faster speed and feed. An improved configuration was designed for more efficient grinding of cutter blades for step threading. Three different materials were tested in threading operations and one was selected based on test results. For additional information, contact D. Dunlap, ARRCOM, (309)794-3270.

Project 7482. Modified Ribbon Rifling Generating Machine. Rifling of gun tubes requires an excessively long honing time. This project will modify the rifler to accept two tubes side-by-side to produce two tubes in the time now needed for one. In-house design and specification work has been completed. Work is continuing in an attempt to solve the problems associated with contract placement. For additional information, contact D. Dunlap, ARRCOM, (309)794-3270.

Project 3444. Fully Additive Manufacturing for Printed Wiring Boards. The present subtractive method of producing circuit boards is wasteful of copper, slow, and expensive. This project will produce circuit boards by a fully additive process starting with a bare board. The wiring pattern will be built up using an electroless metal deposition system. For additional information, contact R. Brown, MICOM, (205) 876-5321.

Project 3445. Precision Machining of Optical Elements. Existing precision machining facilities cannot keep up with the demand, meet optical design requirements, meet production schedules, and stay within reasonable cost boundaries. This project will integrate both the well proven ERDA developed single-point diamond machining capabilities and the developing interferometric aided and computer controlled technology into a manufacturing method. Assembly and tabulation of data on infrared optics has begun. This data is being examined for components amenable to diamond turning. Selection against conventional methods is being made on a cost-performance basis. For additional information, contact W. Friday, MICOM, (205) 876-8611.

Project 7802. Establish Machine Tool Performance Specifications. Procurement, acquisition, and application of new and used machine tools are both physically and economically inefficient. Tests will be designed and procedures established for testing machine tools and determining overall performance efficiency. Guidelines will be written for procurement of machine tools according to specific performance requirements and efficiencies. A methodology was developed and demonstrated for analyzing the relationship of Rock Island Arsenal production requirements to the results of machine tool test procedures. Project results were reviewed with RIA NC programming and plant equipment personnel. For additional information, contact R. Kirschbaum, ARRCOM, (309) 794-5363, or D. Dunlap, (309) 794-3270.

Project 7916. Application of Low Cost Mandrel Materials. To produce a satisfactory substitute for tungsten carbide mandrels and to eliminate sole source procurement. The price of the mandrels has increased fifty percent over the last five years. High speed mandrels have been used for a swage process in United Kingdom. This will be a substitute for tungsten carbide mandrels. For additional information, contact V. Colangelo, ARRCOM, (309) 794-5517, or D. Dunlap, (309) 794-3270.

Project 6693. Ball Propellant Deterrent Coating - CAM Related. The product of the deterrent coating stop in ball propellant manufacturing demonstrates significant variability in charge weight from batch to batch. This project will build a mathematical model of the deterring process and validate it in pilot plant tests using a programmable process controller. Fabrication, assembly, installation, and acceptance testing of the modified 5 gallon reactor and associated programmable process controller were completed. Preparation of the final technical report is under way. For additional information, contact J. Goldman, ARRADCOM, (201) 724-5043, or T. Gropler, MPBMA, (201) 724-2841.

Project 6748. SCAMP Pollution Abatement. The pollutants produced by small calibre ammunition production (SCAMP) lines have been investigated. A recommended abatement system has been tested on a single SCAMP line. Results showed better than expected waste separation. The equipment was accepted. For additional information, contact F. Stulb, ARRADCOM, (201) 724-4851, or K. Wong, MPBMA, (201) 724-4076.

Project 6753. Methods for Orienting and Feeding Small Calibre Ammo. The existing batch process uses slow parts feeders. Feeders initially developed for the 5.56 mm MOD program have had mechanical

problems and have not achieved the required efficiency. This project will utilize new feeder technology to provide feeders with virtually 100% fill capability and improved ruggedness. A cost growth was approved. The process developed by Gulf and Western was accepted and authorization to manufacture was given. For additional information, contact E. Rempfer, ARRADCOM, (201) 724-3737, or B. Hazduczok, MPBMA, (201) 724-2742.

Project 3447. Scale-Up and Demo for the Recovery of Carborane From Waste Propellant. The production of N-hexycarborane (NHC) results in up to 10 percent rejected material because it will not meet ballistic rate requirements. The scrap propellant can be dissolved in pentane, dried, and distilled to purify it. The NHC that would be scrapped is thus recoverable. This project will scale up the laboratory process such that the total process can be demonstrated. For additional information, contact B. Austin, MICOM, (205) 876-2174.

Project 3449. Optional Propellant Ingredients. A number of chemical ingredients used in solid rocket propellants have become unavailable because some of the reagents are hazardous. Studies show that isophronone diisocyanate (IPDI) can be made in a batch process without using phosgene. This laboratory process will be scaled up. For additional information, contact J. Murfree, MICOM, (205) 876-4656.

Project 5019. Tactical Vehicle Storage Battery. The major cause of tactical vehicle battery failure is battery container breakage. This project will provide a new high impact plastic container to increase field performance requirements and to accommodate the maintenance free concept already released in larger military battery sizes. A new plastic container and cover design has been adopted for the military low maintenance battery. A contract was awarded for the fabrication of test batteries. Evaluation will be conducted by TARADCOM and TECOM. For additional information, contact D. Pyrce, TACOM, (313) 574-6722.

Project 7745. Diamond Tool Fabrication Capability. Bonded diamond tooling in optical manufacture witnesses problems with special diamond tool. This project will establish capability for direct in-house fabrication of optical diamond tooling utilizing established powder metallurgy facilities. DARCOM approved justification for continuation of this project, and work has recommenced under a contract with ITEK Optical Systems Division to develop reshaping and/or reforming techniques for diamond pellets. For additional information, contact N. Scott, ARRCOM, (309) 794-6430, or D. Dunlap, (309) 794-3270.

Project 7753. Noise Suppressor for Powder Type Recoil Mechanism Testing Machine. The noise produced by the powder gymnasticators exceeds the levels allowed by Illinois State Regulations. This project will build a portable housing which can be placed over the machine to reduce the noise to satisfy the requirements. Due to circumstances beyond control, this project has slipped. However, the project is being properly managed and success is contingent upon technical feasibility. The equipment design has been accepted and fabrication is nearing completion. The rail system for movement of the noise attenuator and the blower foundation have been completed. For additional information, contact E. Seitz, ARRCOM, (309) 794-6745, or D. Dunlap, (309) 794-3270.

Project 7730. Manufacture of Split Ring Breech Seals. Split rings require precise manufacturing. Present methods are outdated and costly, requiring much hand finishing by highly skilled workers. The rejection rate is high, with much rework. Automated and improved procedures will be adopted - a new method of slitting ring requiring less stock removal. Special equipment will be designed and purchased to minimize hand finishing by high-skill operators. Hydraulic kinking machine fitted with larger cylinder. A contract has been let to modify a wire EDM for splitting the ring. Manufacturers of lapping and polishing equipment were contacted in regard to polishing and seating of the split surfaces. For additional information, contact R. Demeo, ARRCOM, (309) 794-5611, or D. Dunlap, (309) 794-3270.

Project 1003. Low Cost Molded Packaging for Hybrid Electronics. Foam or epoxy potted hybrid circuits used in small caliber ammunition are surviving high G levels. Hermetic packages are not used due to cost considerations. This project will apply molding techniques that are used in dual-in-line plastic packages. This process is based upon bulk film protection of the substrate followed by molding of the electronics and metal plating to provide shielding if required. For additional information, contact A. Goldberg, ARRCOM, (309) 794-3190, or D. Dunlap, (309) 794-3270.

Project 1345. Biological Warning System. There is no biological agent detector mass production capability. This project will utilize PEP data and prove the feasibility of mass production with a minimum of sole source components that must be acquired on a broad base. A contract was awarded to Inter-Mark for pilot tape-making equipment. Ultrasonic welding was determined as best for sealing a nylon tape cassette. Sterility problem of refill kit samples was solved by air jet spraying all bottles before sealing. SRI continued testing of tapes. Inter-Mark system for tape marking has been debugged. Bendix has completed and delivered breadboard detectors. For additional information, contact T. Gervasoni, ARRCOM, (309) 794-4424, or D. Dunlap, (309) 794-3270.

Project 7927. Generation of Base Machining Surfaces. To obtain a distribution of stock on a rough cast component, it is currently necessary to "draw" the finished component on the material using high temperature gage and layout templates. This is done on a table from which the part moves to a machine for similar setup. Using present layout techniques such as optical shadow layout templates, the component can be positioned directly on the machine to establish the first cut, eliminating the initial layout operation. A detailed engineering analysis was performed that led to the selection of an engineering design for the automated system. Work has commenced on a procurement specification for the system. For additional information, contact B. Rose, ARRCOM, (309) 794-5611, or D. Dunlap, (309) 794-3270.

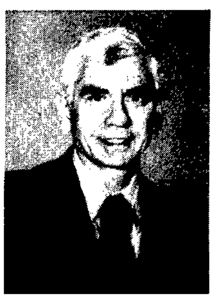
Project 1348. Super Tropical Bleach. There is a major shortfall between the FY78 requirements for this item and the quantity of imported chlorinated lime known to be available. This project will provide the basic design of a super tropical bleach facility. Studies will include pollution abatement and control equipment to ensure compliance with standards. Three feasible processes were identified by Battelle as candidates for production of chlorinated lime. A liquid-liquid double salt process was selected for further study because of distinct advantages over other processes. For additional information, contact J. Szachita, ARRCOM, (309) 794-3943, or D. Dunlap, (309) 794-3270.

Project 7925. Bore Evacuator Boring. Both ends of the bore evacuator have similar diameter bores and require almost equal high cost machining time. Reducting of machining time is imperative. Orientation of the bores is in relation to each other. A special purpose machine and tooling package providing a head for each end of the evacuator chamber can be developed to produce both bores simultaneously. If both surfaces were produced from the same setup, orientation of centerlines would be assured. Two production machines adaptable to this project have been secured and are presently being stored on site. Preliminary design concepts are being evaluated to define suitable work holding fixtures that will adapt to these machines. For additional information, contact C. LaRoss, ARRCOM, (309) 794-5611, or D. Dunlap, (309) 794-3270.

Project 7926. Hot Isostatic Pressing of Large Ordnance Components. Many hours are required to machine a breech block forging to the finished part. More than 25% of forging becomes chips. With the high cost for alloy steel, this becomes a very costly waste of material. Hot isostatic pressing (HIP) will form breech blocks to nearly final shape, greatly reducing machining costs. Quotes have been obtained from capable HIP vendors to produce test billets. Contracts are being negotiated. For additional information, contact P. Thornton, ARRCOM, (309) 794-7926, or D. Dunlap, (309) 794-3270.

Important Changes at AVRADCOM

ManTech Implementation Update



GERALD A. GORLINE is a graduate Industrial Engineer with BSIE (1959) and MSIE (1966) degrees from Washington University, St. Louis. He currently is assigned as Manager of the AVRADCOM Productivity Improvement Program. He has been responsible for managing the AVSCOM and AVRADCOM Manufacturing Technology Program during the past fourteen years. In addition, he has served as project engineer for the development of advanced manufacturing technology projects for CAD/CAM and engine and aircraft components used in Army helicopters. He has twenty-two years of manufacturing engineering experience, of which nineteen are in the aerospace industry involving both fixed wing and rotary wing manufacturing areas with aerospace firms and with the U.S. Army. He is active with the Aerospace Division, American Institute of Industrial Engineers, and the American Helicopter Society. He also is a member of the Metals Committee of the Tri-Service Manufacturing Technology Advisory Group (MTAG).

A previous article appeared in Volume 6, Number 1, 1981, of the U. S. Army ManTech Journal titled "Implementation of AVRADCOM MM&T", in which this author outlined the steps being undertaken by the U. S. Army Aviation Research and Development Command to put new technologies developed via MM&T projects into production lines. An update of the procedures would be appropriate at this time.

The basic steps outlined in the previous article still exist (Figure 1). However, several changes have occurred. These changes in the AVRADCOM implementation procedure are depicted in Figure 2, Steps 2 and 3.

Built In At Start

Gerald Nadler, Professor of Industrial Engineering at Wisconsin University, indicates in his publication,

NOTE: This manufacturing technology contracting procedure is being implemented by the U.S. Army Aviation Research and Development Command under the overall direction of the U.S. Army Office of Manufacturing Technology, DARCOM. The AVRADCOM Point of Contact is Mr. Gerald Gorline, (314) 263-1625.

"Work Design", that if you want to get a new system or procedure implemented, you must get everyone concerned with the change or establishment of a procedure involved at the start. This is the philosophy of the AVRADCOM MM&T Project Implementation procedure. In other words, build in implementation at the start of the project; get everyone involved; and get all the foreseen approvals necessary for putting the technology into production before you start the Project Execution phase (Figure 3, Step 3). If you cannot get the known obstacles approved in advance, do not start the project!

CYCLE

Formulation to Implementation
MMT Project
(Generic Process With Known End Item)

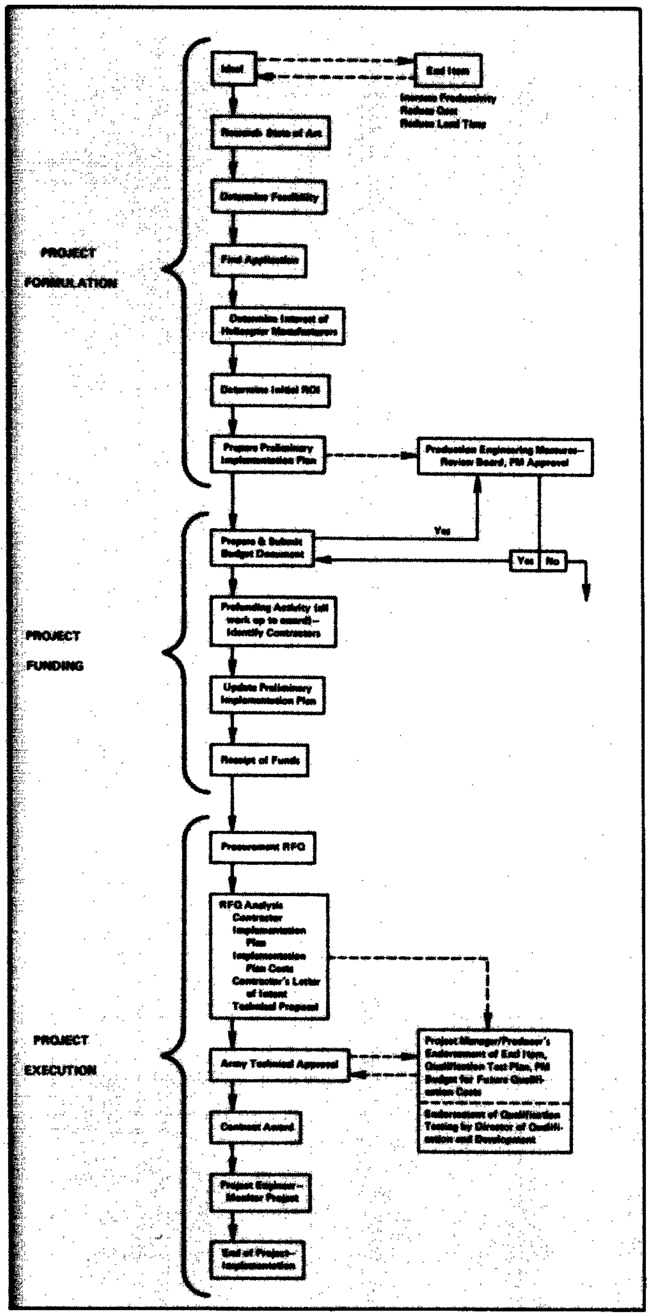


Figure 1

Implementation Plan Comprehensive

The Implementation Plan outline requested as part of the initial solicitation and depicted in Figure 3, Step 2a, and Figure 4, should identify as a minimum ALL the efforts and associated costs of each required from start of the project (Execution Phase) to Implementation of the Technology. For example, the MANTECH effort, qualification testing and the production equipment/tooling required. This will also include any subcontracting effort.

Statement of Intent Firm

A letter of intent to use the technology in the contractor's or subcontractor's plant during production will be submitted with the contractor's reply to the solicitation. This Statement of Intent to use the technology must be signed by an appropriate high ranking company authority. Time and dollar values for each phase depicted in Figure 4 are required as part of the Implementation Plan. An update of the Implementation Plan during the Project Execution phase and after completion of the project will be made by the contractor.

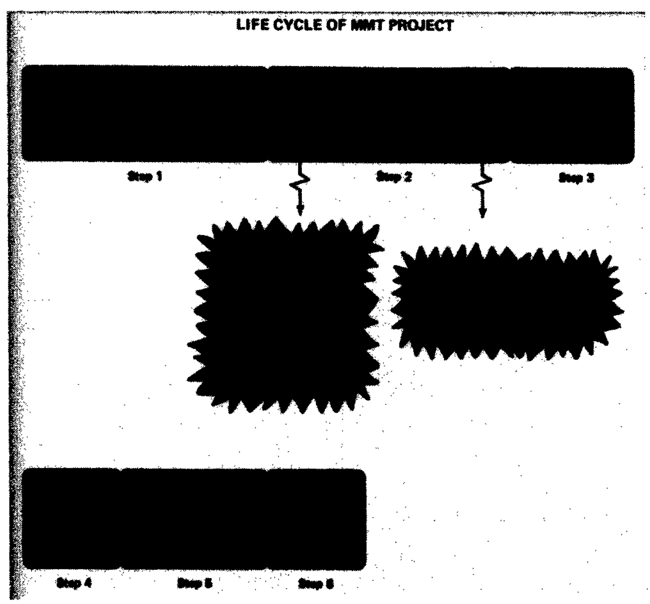


Figure 3

NOTE: A brief outline of AVRADCOM's Project Work Directive is presented on the following page.

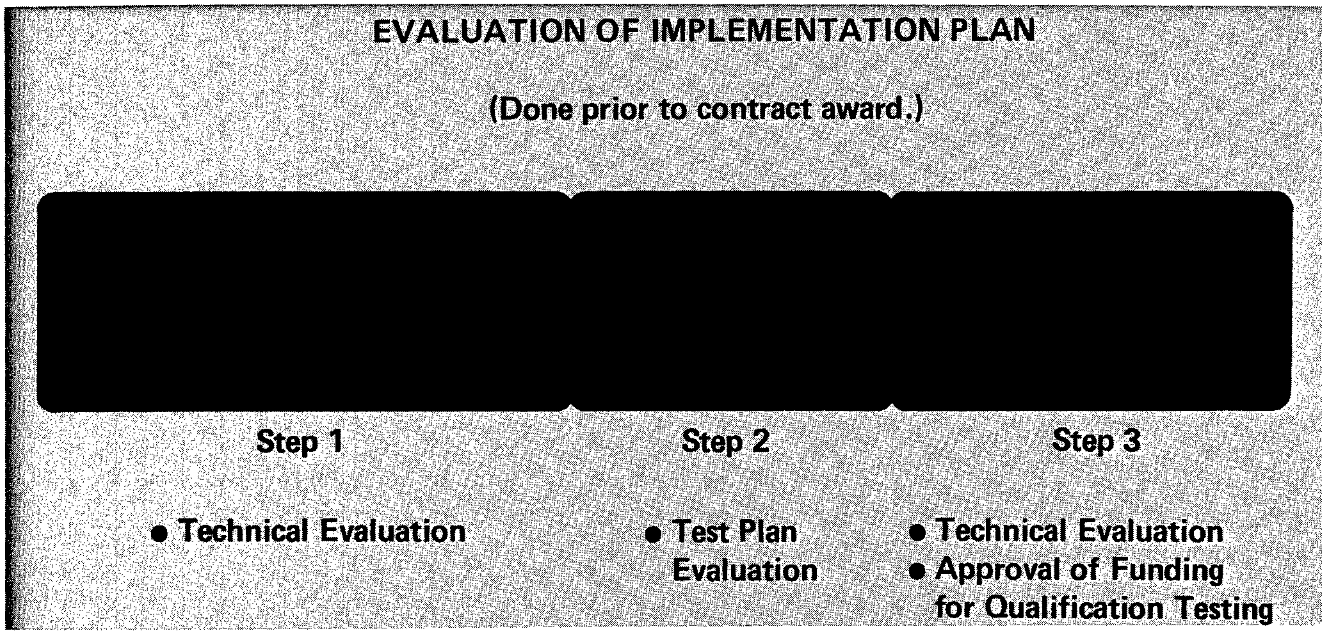


Figure 2

Top Management Participates

The major change to the AVRADCOM implementation procedure as compared with the previous article in Vol. 6, No. 1, is depicted in Figure 2, Steps 2 and 3. This new requirement is to get the appropriate project/product office and the Qualification and Development representatives to participate in the evaluation of the Implementation Plan returned with the solicitation.

Project Engineer Creativity Needed

Implementation for any related efforts will be pursued by the AVRADCOM Project Engineer in conjunction with Project Execution—e.g., application related to a new or existing aircraft system which was not included in the original plan; or if circumstances occur during project execution that affect the anticipated implementation date, the Project/Product Manager and other users will be contacted. A new anticipated implementation date will be established and the Project/Product Manager's support will be resolicited.

The procedure outlined herein looks simple, but a lot of creativity and effort is required of the performing activity and the AVRADCOM Project Engineer to make MM&T implementation a reality.

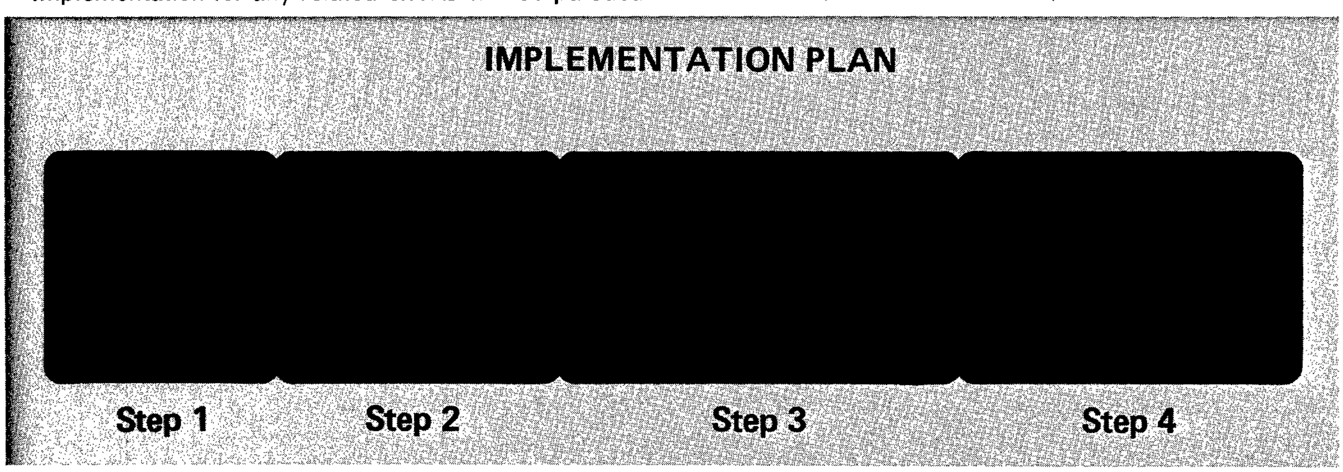


Figure 4

PROJECT WORK DIRECTIVE
(Requirements for Typical AVRADCOM Project)

1. Statement of Work

   The contract shall be broken down in ____tasks:
   a. Task I (description)
   b. Task II (description)
   c. Task III (description)
   Etc., etc.

2. AVRADCOM Project Engineer

3. Milestone plan of performance—required within 45 days of receipt of PWD

4. Other Requirements
   a. Contractual
      (1) Copies of solicitations furnished AVRADCOM
      (2) Solicitation will contain a contract clause regarding predetermination of rights in the technical data.
      (3) Solicitations to include:
         (a) Manufacturing Methods Report
            (1) Contractor Performance Plan
            (2) Scientific and Technical Report
               (a) Letter Progress Report
               (b) Manuscript of Draft, Final/Interim
               (c) Reproducible Report Copy, Final/Inter.
               (d) Executive Summary Report, Final
            (3) Performance and Cost Report
         (b) Technical Data Package
         (c) Process Specification
         (d) Part, Component or Subsystem Test Plan(s)
            (1) Material Tests
            (2) Mechanical and Material Tests
         (e) MM&T Implementation Plan
         (f) End of Contract Briefing
         (g) Drawings, Engineering & Associated Lists
         (h) Progress/Status Meeting Report
         (i) Records, Still Photographs
         (j) Others – (as required)
            (1) Safety Analyses for Airworthiness
            (2) Airworthiness Qualification Data (Mil. Std.)
            (3) Weight and Balance Data

   b. Visual Aids
      (1) Displays/Models – if suitable; within 30 days of project completion
      (2) Photographs, Viewgraphs, and Sample Items
         (a) Before and After Illustrations; where photos not practical, use artist's sketches
         (b) Photos of Program Accomplishments
      (3) Movies/Video Tape – where practical; brief
      (4) Sample of Items

   c. Implementation – end of project briefing will formally present project results for technology transfer.

   d. Reports – Progress Status
      (1) Semi-annual Project Status Reports
      (2) Milestone Charts – Total Perspective
      (3) Periodic technical briefings – (discretionary)

   e. Reports – Interim and Final
      (1) Interim Technical Report – required when each fiscal year's funds are fully expended.
      (2) Final Technical Report – at project completion
      (3) Requirements for (1), (2) Specified
      (4) Report Distribution List – Government, Industry
      (5) Final Report Draft Review, Approval
      (6) Final Report Covers, Preface Sheets Specified
      (7) Contractor Material, Process, Fabrication, and Manufacturing Specifications – Vol. II of Final Report (restricted distribution)
      (8) Executive Summary of Final Report
      (9) Economic Analysis –cost comparisons and projections, cost/quality tradeoff opportunities
      (10) Final Report by Performing Government Activity on In-House Work or Work Performed by the Contractor(s)
      (11) Article suitable for Publication

   f. Project Execution–Project Reviews Conducted:
      (1) Planning
      (2) DARCOM Quarterly Reviews
      (3) End of Program Briefing
      (4) Program Progress Reviews – within 6 months after project initiation

   g. Project Rejustification
      (1) Extention of Incomplete Projects – after 3 years
      (2) Justification Inclusions
         (a) Project Number
         (b) PA 1497 (MMT) or 1499 (MACI)
         (c) Cost Data
         (d) Title of Project
         (e) Facility/Contractor and Location
         (f) Justification for Continuation
            (1) Project Status
               (a) Funds Obligated
               (b) Funds Expended
            (2) Work Accomplished
         (g) Work to Be Accomplished
         (h) Amount of Extention Required (date)

5. Clarification of Requirement – from Project Engineer

6. Additional Requirements
   (1) Implementation
      (a) Implementation Plan – Part of Initial Solicitation All efforts required, including subcontractor. A letter of intent to use the technology in the contractor's or subcontractor's plant during production approved by high official of company.
      (b) Evaluation of Implementation Plan by Appropriate Project/Product Office and Qualification and Development Representatives
      (c) Implementation for Related Efforts – Pursued by AVRADCOM Project Engineer in Conjunction with Project Execution

Quality Assurance at Production Rates

Automated Knurl Inspection for Rockets

by
Eugene George
Project Engineer
Chrysler

After assembly of a warhead to its propulsion system (rocket motor), it is imperative that these two items remain locked together during launch and flight. Traditionally, course threads screw the warhead onto the rocket motor and a knurled surface is used as a locking aid in the process. Recently, Chrysler-Huntsville's Electronics Division has developed an optical, semiautomated prototype knurl inspection system for the U.S. Army Armament Research and Development Command.

Currently, 155-mm rounds are not being knurled; however, the larger 8-inch rounds are being knurled and therefore require inspection. This inspection system is a prototype and proof-of-principle instrument for the 8-inch round.

Twenty Seconds Per Surface

The optical knurl inspection system is a standalone test unit designed specifically to inspect knurl surfaces of 155-mm (M549A1) rocket assisted projectiles (warheads) and motors. Consisting of an electronic/pneumatic console and optical measurement unit, it operates on 110-120v ac at 1000 watts and requires an air supply of 75 psi at 1 cfm. Further, it displays the number of radical grooves and the number of acceptable knurls, and, through preselectable tolerance switches, has adjustable limits for added versatility.

Inspection time is 20 seconds per knurl surface not including loading, unloading, and rewind time. Optical resolution is approximately ± .0006 inch.

Knurls Viewed by Scanners

The optical knurl inspection system consists of (1) a rotary scanner optical assembly that illuminates and scans the knurl surface; (2) an electronic unit that interfaces with a computer which processes scanned data, compares derived parameters with preset limits to make Go/No Go decisions; and (3) a mechanical housing with a pneumatic chuck to hold the round. Also, an output port is available for logging statistical pass/fail data. The electronic

NOTE: This manufacturing technology project that was conducted by Chrysler-Huntsville was funded by the U.S. Army Armament Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AVRADCOM Point of Contact for more information is Donald Fischer, (201) 724-6714.

scanner and optical system are rotated about the round, which is secured by the pneumatic chuck. Each radial row of knurls is viewed by a pair of electro-optical scanners, while the locking knurl surface itself is illuminated with intense white light at a 45-degree angle. Two optical relay systems provide images on self-scanning linear photodiode arrays.

General Automation 16/45 computer is required for operation of the system, and was used only for in-house testing and demonstration; it was not included as part of the contract.

Optics, Mechanics, Electronics Combined

The optical housing assembly (Figure 1) includes the scanner assembly and optical package, which are mounted on a rotating platform. The lower end of this platform is attached to a pair of preloaded angular contact bearings. When a round is lowered in the top of the machine, a plate which is pneumatically raised holds the round until a pneumatic chuck clamps it in position. The plate then drops out of the way and the scanner platform begins to rotate. The knurl surface is illuminated by a 100-watt quartz iodine lamp, fiber optic relay, and a projection optical system. A pair of very fast aspheric lenses focuses the energy from the fiber optic onto the knurl surface.

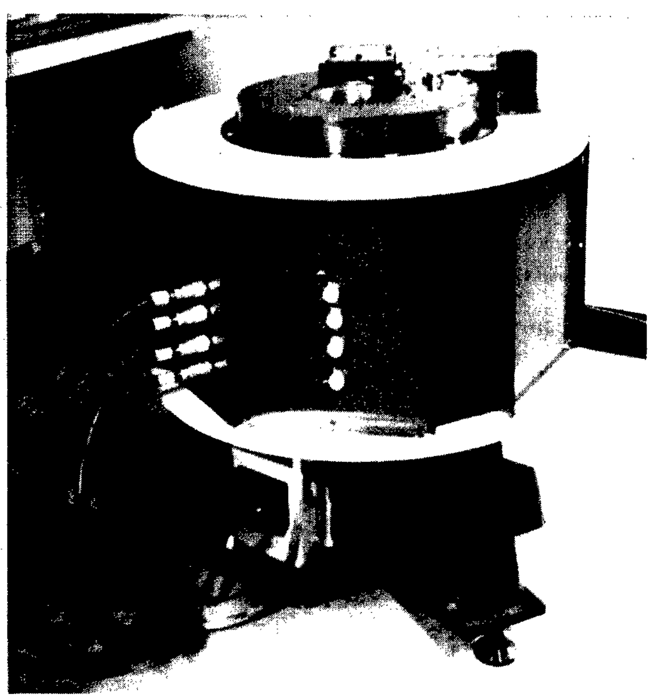


Figure 1

Two optical systems—a side view system and an end view system—image the knurl surface on linear photodiode arrays. The side view system looks down each row of radial knurls, and is like observing six 90-degree pyramids in a row with one face toward the viewer (Figure 2). The depth of field is short enough that only the outside full height pyramid is in sharp focus. In addition, the optical magnification is adjusted so that each photodiode represents exactly 0.0005 inch of knurl height. This technique provides a direct electro-optical measurement approach to knurl height and circumferential pitch.

The end view optical system looks head on at the knurled surface. Its optical magnification is adjusted so that each pyramid represents 64 photodiodes in the radial direction. The photodiode array is aligned to scan one radial row of knurls at a time—that is, a row of peaks, valleys, or sides. The signal from this array is processed to determine knurl integrity along a radial row. An optical shaft encoder is mounted directly on the bottom of the scanner platform.

The linear photodiode arrays selected for this system were 256 and 1024 element arrays by Reticon. The computer used was a General Automation SPC 16/45 minicomputer, and a magnetic tape unit was used for program storage. In end view electronic processing, the video is first processed with a level comparator and then converted to a 256-bit word. A first-in, first-out (FIFO) memory then stores the word until it is loaded into computer memory.

The side view system is the synchronizing element for the data acquisition process. Again, the video signal is processed by a level comparator and the width of the output pulse is measured (Figure 3). The data buffer then locates and stores the peak and valley outputs. The measurement of the angle of rotation is accomplished by an optical shaft encoder and a photodetector. All data is transferred to the computer for processing. The computer program with the aid of a real time operational input/output system will perform the following basic functions: process side view data, process end view data, process optical shaft encoder data, make decisions, and handle I/O operations.

A Reliable System, With Improvement

This system has successfully demonstrated the application of state of the art electro-optical technology to

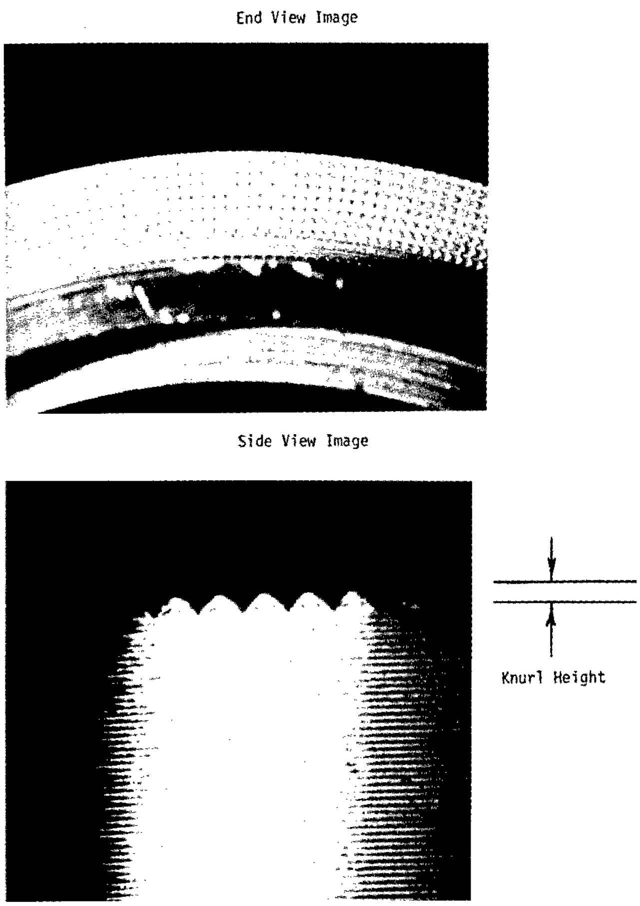


Figure 2

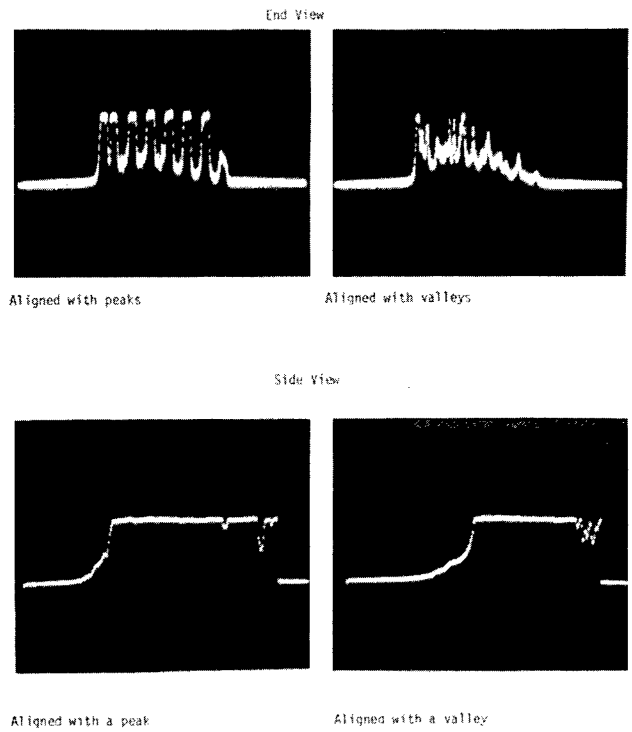


Figure 3

inspection of artillery projectiles, and tests have shown that critical defects can reliably be detected, measured, categorized, and displayed. Subsystems have been integrated and testing begun, but system debug and checkout was not completed. Testing has also indicated that performance of the electronics could be improved by synchronizing the strobe clocks for the end view and side view photodiode arrays. This approach would reduce the cross coupling (cross talk) of clock pulses between array processors.

Optics Modification Needed

Although the optical system functioned very well, the light output through the 48-inch-long fiber optic coupling is sufficient but not optimum. A two to three fold increase in available light would increase the signal-to-signal noise ratio. The light source is presently a 100-watt quartz halogen lamp. An increased light intensity would also allow a sharper cutoff on the optical image of the inside row of knurls. And, because this optical system is designed specifically for the 155-millimeter knurl surface, extensive modification would be required to inspect 8-inch surfaces.

Development Suggested

The structural and mechanical package proved to be extremely rugged and stable. The rotary mechanism functioned well, while the limit switches provided ample adjustment. Further, the pneumatic components and projectile holding apparatus operated flawlessly. It should be noted that a vernier adjustment mechanism for centering the chuck would be very helpful for initial setup. In contrast to the optical system, the rotary mechanism would adapt easily to the larger 8-inch round. However, the structural members and chuck assembly would require a complete redesign.

Phase I Induces Program Revisions

MT for Traveling Wave Tubes

ALFRED F. MARSILI is an Electrical Engineer in the Manufacturing Technology Division, Systems Engineering Directorate, of the U.S. Army Missile Command. Prior to joining the Missile Command in 1980, he worked for the USAF at Robins Air Force Base for four years in ATE of microwave equipment. He also worked for ten years at Teledyne Brown Engineering Company, Huntsville, in support of NASA Projects. He also worked eight years for the Hallicrafters Company of Chicago, on ECM projects for the U.S. Air Force. He also worked three years at the University of Chicago as a research engineer in the Institute for Nuclear Studies.

Results of the first phase of a three phase manufacturing technology program by the U. S. Army Missile Command brought about extensive changes in plans for Phases II and III, reducing production costs and providing more effective hardware than originally anticipated.

The object of the first phase of a three phase Litton Industries MM&T program sponsored by MICOM was to design and build one or more traveling wave tubes (TWTs) utilizing a ring loop RF circuit. It also was to comply with military specifications regarding bandwidth, duty cycle, and saturated power and gain.

The intent of the complete program was to establish manufacturing technology for such a TWT for a specific missile borne application. The program's goal was a cost reduction to $4000 per tube at a production rate of 100 tubes per month in quantities of 3000 to 6000. Upon successful completion of this basic effort, the Government proceeded with the second phase, which included development of a fast cathode warmup gun, qualification test, design of pilot production line, and delivery of two final model qualified tubes along with reports and data.

Opportunities for Cost Reduction

The results achieved on the first tube with a shadow gridded gun provided so much margin in the performance of the tube that it was possible to consider significant cost reductions in the design and fabrication of this tube. For instance, the stability margin of the helix input circuit and the small size of the beam (indicated by the need to shunt the magnetic field excessively to regain the normal small signal gain) suggested strongly that a single section, alumina rod-supported circuit of significantly smaller diameter than that used with the boron nitride rods could be substituted for the two section, more costly boron nitride-supported circuits. An analysis on the computer indicated that this substitution would work.

Two Tubes Built and Tested

Two tubes were fabricated and tested; the first was later regunned with a shadow gridded gun which replaced the intercepting gridded gun. The elements which were common to the two tubes were helix input, ring loop output, with a stainless steel vacuum envelope having brazed-on pole pieces to be used with samarium cobalt magnets for beam focusing. The first tube used APBN support rods for the helix input and round BeO support rods for the ring loop output.

The power and gain test results achieved with the first tube showed that the tube matched the computed design with respect to design performance parameters and also appears to meet all of the gain and power specifications. This initial evaluation included gain, gain flatness, power, duty, transfer linearity, and IM products. The swept signal gain (power out at -22dBm drive) was measured at three beam voltages: 7.37, 7.50, and 7.65 kV (Figure 1).

NOTE: This manufacturing technology project that was conducted by Litton Industries was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorae for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Bobby Austin, (205) 876-2147.

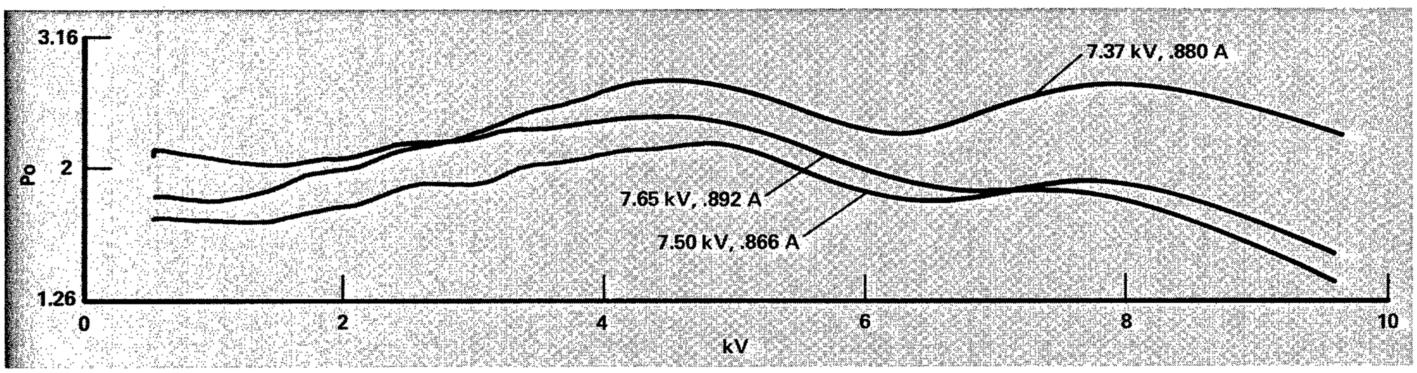


Figure 1

The maximum gain variation across the band occurs at 7.65 kV and is about 2.25 dB. Mid-band gain is approximately 75 dB.

Transfer curves for low, middle, and high band for the same three values of beam voltage showed that the optimum grouping of curves at saturation occurs at the highest of the three voltages—7.65 kV, whereas the minimum small signal gain spread occurs at the lowest of the three voltages—7.37 kV. This is typical of the performance of TWTs with ring loop output circuits. The best overall performance is achieved at the higher voltage.

This was further illustrated by examining swept saturation curves for three values of power drive: -5, -7, and -9 dBm input. The power spread at any given frequency did not exceed .3 dB, and the spread from band edge to band edge did not exceed .4dB. Transfer linearity was studied at eight frequencies across the band. Maximum compression was .55 dB near the low end of the band, while maximum expansion was .2 dB at the high end.

Beam transmission with the tube driven to saturation and depressed 40 percent exceeded expectations. The maximum interception at the 7.65 kV beam voltage with .892 amp of beam current was 170 milliamps; this is about half of the maximum allowed by the specification. Also, the tube was operated overnight at 6 percent duty (above specs) while being swept across the band at saturation drive and depressed to the maximum value of 40 percent. There was no indication of change in performance after this aging cycle.

Second Tube Discontinued

A second tube was built with beryllia rods for support of the output circuit in place of the rectangular boron nitride rods. The ring loop circuit velocity (circuit pitch) dictated by the computer turned out to be too fast for this tube, with the result that both the gain and power at the designed operating voltage were low and both gain and power increased at operating voltages in excess of those allowed by the specification. Because this tube was a backup for the (first) boron nitride tube and showed problems during testing, the beryllia rod tube was discontinued. The boron nitride tube, S/N 2001, was so successful that a backup was not considered to be needed.

Transmission Efficiency Leaps Up

The intercepting gridded gun in the first tube was replaced by a shadow gridded gun which was intended for the final design in the second phase of the program. The shadow gridded gun is of a smaller cathode diameter, lower area convergence design in which the .350 inch diameter cathode is replaced by a .30 inch diameter cathode; the latter is more suitable for conventional fast warmup.

The transmission achieved with the shadow gridded gun was the best ever experienced at Litton. The tube turned on with neither shunt nor magnet rotation at approximately 99 percent beam transmission. A half dozen shunts brought that transmission to 99.7 percent. That is 2 milliamps of interception out of 864 milliamps of beam current, which compares with 34 milliamps of interception under like conditions using the intercepting gridded gun.

The transmission was checked at beam voltages from 6.5 to 8.0 kV and at beam perveance from 1.1 to 1.5 and found to exceed 99 percent beam transmission under all of these conditions.

Cost Reductions Possible

Three cost reduction options were considered during the second phase of the program:

(1) Substitute a single alumina rod-supported helix section for the APBN rod-supported sections of the baseline tube. This reduced the number of rods, the number of loss lumps, the number of barrel sections, the number of weld flanges, and the number of helices wound.

(2) Substitute a squeezed, dispersion hardened copper barrel for the thermally inserted stainless steel barrel in both the input and output sections.

(3) Substitute low cost mish metal magnets for the samarium cobalt magnets.

From Fabrication to Pilot Production

The second phase of this project included fabrication and delivery of traveling wave tubes which utilize a ring RF circuit. In addition, a pilot line capable of producing 100 tubes per month was designed for the production of TWTs. Flow sheets, plant layouts, and production data necessary to ensure production at the desired rate and cost were also prepared, and a plan was developed for providing the capabilities of the pilot line at a reduced rate.

At the beginning of this phase, the basic RF circuit and electron gun designs had been developed and tested. The most important tasks that remained were to

- Develop and evaluate a reliable fast warmup cathode assembly

- Package two tubes and subject them to the full Acceptance Test Procedure including random vibration and shock.

Fast Warmup Emphasized

Because the optics of the shadow gridded gun had been demonstrated, this gun was used with only minor changes in all of the tubes built during the current program. It has consistently provided excellent beam transmission; thus, the effort in the gun area has been concentrated on achieving the fast warmup capability.

A number of cathode heater assembly configurations were investigated before arriving at the design used in the tubes that were submitted for acceptance testing. In all cathode assemblies that were used in this option, the emitter was a tungsten-iridium matrix type. This emitter was chosen because of its current density capability and a required operating temperature that is approximately 100 C lower than that of a pure tungsten matrix emitter.

The initial cathode heater assemblies of this phase used a photoetched flat pancake heater mechanically sandwiched between the matrix cathode and a similarly shaped molybdenum cup. The cup and cathode had been

flame sprayed with alumina to provide electrical isolation. Several assemblies were fabricated and tested. All failed during fast warmup cycling tests. The reason for failure appeared to be insufficient contact between the heater and cathode as a result of the pancake heater's failure to conform to the curvature of the cathode.

Next, a cataphoretically coated tungsten-rhenium wire was used as the heater. As before, the heater was mechanically sandwiched between a flame sprayed cathode and cup. The inability of the cataphoretic coating to remain intact during the fast start cycling led to turn-to-turn shorting and subsequent failure. At that point, other materials and processes that might yield an improved dielectric coating were investigated.

Assembly Procedure Determined

As a result of the many problems associated with the various configurations and materials tested, a complete reevaluation of the assembly procedure was made. From this a specific procedure evolved.

An unimpregnated tungsten-iridium cathode and the support cup were flame sprayed with pure alumina. The heater-cathode package was potted and sintered at a temperature of 1850 C. Then, the button was impregnated and the support sleeve brazed on. An isometric representation of this assembly is shown in Figure 2.

The first assemblies built according to this procedure were tested to determine steady state temperature, steady state current stability, and time to achieve steady state temperature.

Tubes Get Dual Evaluation

Nine tubes were evaluated at Litton. Of these, five were reworked by a gun replacement. All tubes contained the same RF structure—helix input supported by APBN rods and a ring loop output, also supported by APBN rods. Each contained a shadow gridded electron gun. Major differences were in the cathode assembly construction, type of collector, and SAES getter inclusion. Two of these tubes were delivered to Raytheon for a full evaluation. Both tubes were tested in accordance with a mini-accept-

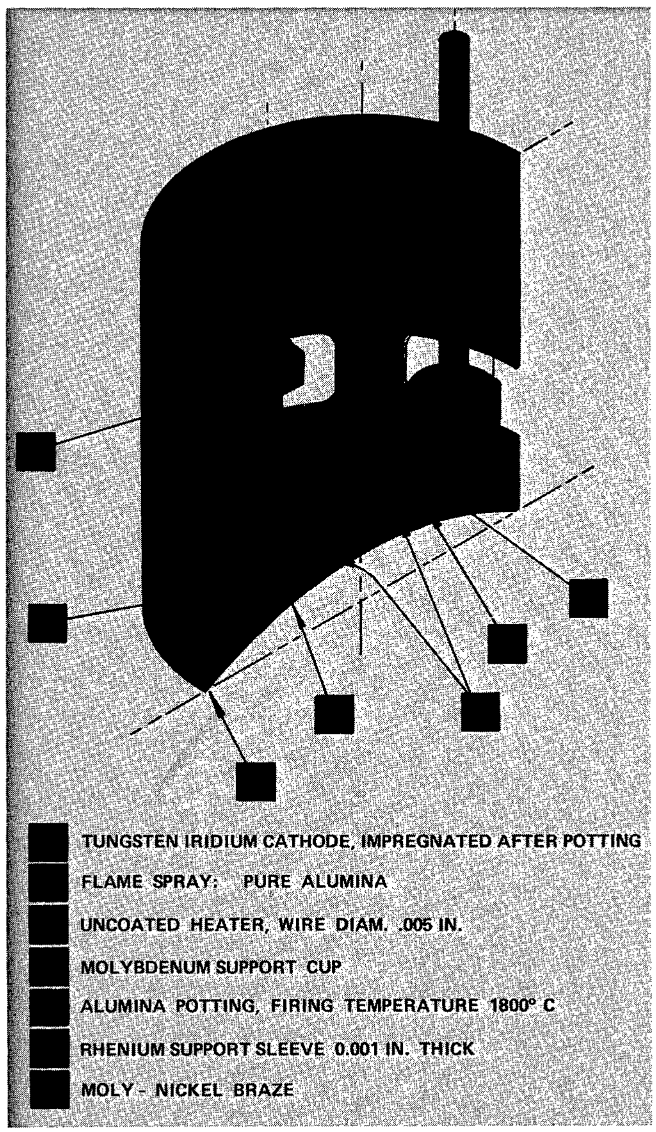


Figure 2

ance test procedure which defined key parameters, voltages, currents, power, gain, and fast start before testing in the vibration and shock environment.

Table 1 shows the point-by-point measurements made at Litton with tube S/N 2006 and the same measurements from Raytheon's full Acceptance Test Procedure with the same tube. This comparison shows good agreement between two independent test sets. This is a very important point since such agreement often is not the case. The parameter which appears to have the greatest discrepancy is saturated output power; but, at F8 +340 where the difference is greatest, the difference is only 0.45 dB.

Manufacturing Methods Considerations

The pilot line was integrated into the existing Litton organization and facilities. The pilot line was organized within the existing organization by addition of or transfer of personnel as required for a production rate of 100 tubes per month. The Litton engineering, manufacturing, and quality control organizations now are set up to handle rapidly changing requirements, with small and large production rates occurring simultaneously on different product types without change in organizational structure. This is accomplished by increasing and decreasing the work force to meet changing requirements.

Process Flow and Plant Layout

A preliminary estimate of the floor space required for manufacturing 100 tubes per month was prepared; the total area was estimated at 12,260 square feet. In preparation for production, the tube was described by a documentation package which contained all the information necessary to manufacture the tube. The master bill of material was stored in a program of the large computer used for all the production control operations. The bill of material contained a listing of all drawings for piece parts and assemblies, jigs, fixtures, and special tooling. In addition, the assembly, test, and processing of software (procedures) required for manufacture were listed either on the bill of materials or on individual drawings.

TEST	LINEAR GAIN AT 2.14 Po		RF OUTPUT AT SATURATION		RF INPUT AT SATURATION		GAIN VARIATION 5.4 Po : 2.14 Po	
	L	R	L	R	L	R	L	R
Unit Frequency	db	db	—	—	dbm	dbm	db	db
F8 + 430	77.1	77.7	14.86 Po	16.2 Po	-10.5	-10.5	-0.3	0.0
F8 + 280	76.6	76.2	14.8 Po	16.1 Po	-8.6	-8.6	-0.3	-0.2
F8 + 340	77.0	77.2	14.86 Po	16.8 Po	-9.7	-9.7	-0.4	-0.3
F8 + 520	77.8	77.9	14.86 Po	16.4 Po	-11.3	-11.3	-0.3	-0.0
F8 + 610	77.8	77.1	16.31 Po	16.6 Po	-10.7	-10.7	-0.3	-0.1
F8 + 730	77.0	77.2	16.31 Po	16.7 Po	-11.9	-11.9	+0.1	±0.3

LABEL PARAMETERS

	SPECIFICATION LIMITS	LITTON	RAYTHEON
RF Input at 12 Po	0 dbm (max)	-13	-16.6
Cathode Voltage	-7.3 to -7.9 kV	-7.7	-7.7
Cathode Current	550 MA (max)	535	540
Grid Drive Voltage	140 to 200 V	166	168.5
Heater Voltage	6.0 to 6.6 V	6.3	6.3
Heater Current	2.0 A (max)	1.61	1.58
Grid - Off Bias	-125 V (max)	-120	-125

Table 1

A proposed material flow plan was also established. For each operation in this plan, there was a standard Litton procedure to document fully the operation. Most of the standard procedures in effect were applicable to the proposed tube without change. All procedures in the development cycle were reviewed and modified where required to make them fully applicable to the tube.

Existing Facilities Adequate

In the third phase of this program, work was continued toward improving fast warmup performance of this tube. Emphasis was placed on reduction of temperature differential between the heater and cathode button by improved potting procedures. The twenty finished tubes were built within Litton's existing operation, after the necessary design and manufacturing documentation were completed. All of the operations that were needed to fabricate the initial quantity of tubes already existed within Litton's manufacturing organization.

Ideal For Thick Sections

Rubber Cure Cycles Reduced By Microwaves

WILLIAM F. GARLAND is a Chemist in the Materials Evaluation Branch of the Engineering Directorate at Rock Island Arsenal, Illinois. He holds a B.A. in Chemistry from St. Ambrose College. He has over 30 years of experience in rubber, plastics, and fiber technology. Currently, he is a Team Leader of the Analytical Laboratory and Radiological Protection Officer at Rock Island Arsenal.

Photograph

Unavailable

Results from an in-house manufacturing technology project at the Rock Island Arsenal have demonstrated that the use of microwaves to preheat rubber compounds can significantly reduce the cure time for thick items and that the product possesses mechanical properties equal to or better than those obtained conventionally.

Large Sectioned Items Slow to Cure

The conventional manner of molding within the rubber industry is to roughly shape the object, transfer it to a mold, and then place it in a heated press. The function of the press is to raise the rubber to the cure temperature and hold it at this temperature under pressure for a period of time to cure the item. Because of the low thermal conductivity of rubber compounds, relatively large sectioned items are slow to cure and do not acquire an optimal degree of cross linkage over their entire cross sectional area without a lengthy cure cycle.

It has been known for some time that heat can be generated quickly inside a mass of some types of rubber compounds if they are placed in a high frequency alternating electric field. Heating by electromagnetic means becomes the only method which can place heat into the middle of the item and therefore has potential for achieving an even temperature distribution through its cross section. Within the electromagnetic spectrum, microwaves are in general the most convenient radiation to use.

This in-house production engineering effort was aimed at providing a means of utilizing the rapid heat generating characteristics of microwaves in the manufacture of rubber components for weapons.

Power Output and Frequency Determined

At the time this project was initiated, there were nine manufacturers of microwave equipment for the rubber industry. Analysis of literature and equipment specifications from several of these manufacturers indicated that the majority of applications favored a 10 kW or less power output at a frequency of 2450 MHz. The attenuation which rubber offers to this frequency would depend on the specific compounding ingredients in the rubber. In general, however, half power depth of 5 to 10 cm were found

NOTE: This manufacturing technology project that was conducted at Rock Island Arsenal was funded by the U.S. Army Armament Materiel Readiness Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRCOM Point of Contact for more information is Mr. W. F. Garland, (309) 794-5039.

to be common. This gives a useful thickness to the component which can be heated at this frequency of 15 to 20 cm. These penetration depths cover most of the heating requirements one would expect within the rubber industry. Based on this information, a 2.5 kW microwave generator coupled to a multimode cavity oven was selected for evaluation in the microwave processing of rubber end items. The microwave oven used in the investigation is shown in Figure 1. The oven, which is 6 by 3 by 2 feet, has 2 cubic feet of working capacity and a 22-inch turntable.

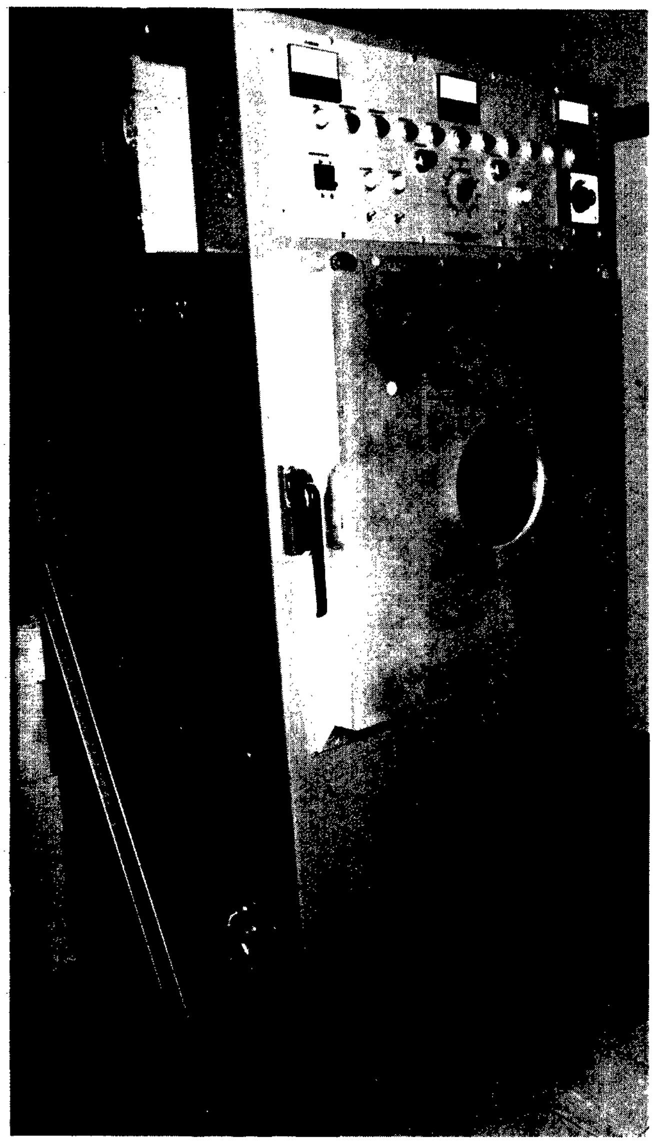


Figure 1

Weapon Components Selected

The 175mm obturator pad (Figure 2) used in the M174 gun mount for the M110 Self Propelled Howitzer was selected for study because it has a relatively large cross sectional area and is 1-3/8" thick. Figure 3 shows the time-temperature relationship between several frequently used uncompounded rubbers which were heated at 2450 MHz. It should be noted that the polar rubbers CR (neoprene) and NBR (nitrile) heat rapidly and reach 200 C in 30 seconds or less, while the nonpolar rubbers NR (natural) and SBR (styrene-butadiene) barely heat up. Compounding of nonpolar rubbers with carbon black normally produces a compound capable of being rapidly heated by microwaves.

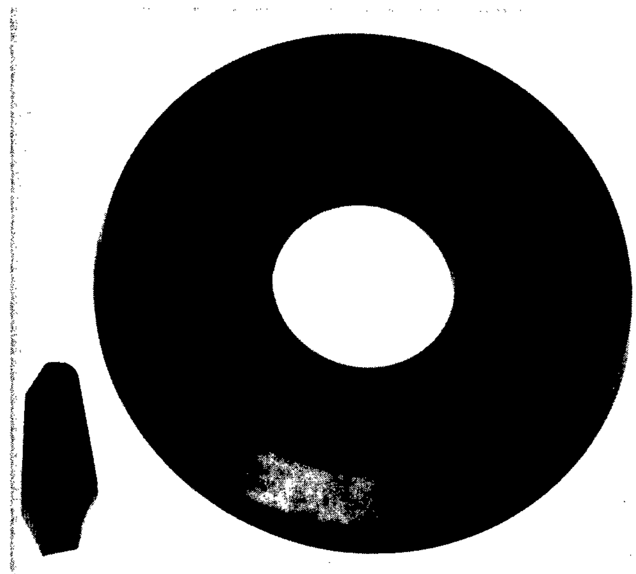


Figure 2

Production Sequence for Obturator Pads

Conventional production of obturator pads begins when the polar polymer CR (neoprene) and other compounding ingredients are mixed in a Banbury mixer. Normally, for large batches, a Banbury mixer offers a short mixing cycle with good homogeneity. After mixing, the rubber is sheeted out on a two roll mill and cut into 2 inch strips which are then fed into an extruder. The extruded rubber compound is preformed to fit the obturator pad mold cavity, then compression molded. Normally, three pads are made at one time in a steam heated press at 290 F for 2

hours. This lengthy vulcanization time for the thick sectioned obturator pad seemed to be a made-to-order test vehicle for microwave preheating and resultant lower cure time.

For the new vulcanization process, experiments were performed to determine the various parameters that would duplicate the degree of vulcanization achieved with the conventional process. An equivalent state of vulcanization was obtained with a microwave preheat time of 4-1/2 minutes at a power of 0.8 kW and subsequent compression molding in a steam press at 290 F for 30 minutes. These experiments revealed that microwave preheating was feasible and that vulcanization time could be reduced by approximately 75 minutes.

Field Testing

While the laboratory work proved the feasibility of the use of microwave preheating for thick sectioned items, testing of items made by any new process must be proven in the field.

The initial field evaluation was carried out with an M110 howitzer at Fort Sill, Oklhahoma. In this test, a microwave preheated obturator pad was substituted for the field issue pad in an M174 gun mount. The test obturator pad was subjected to a total of 925 rounds. The scratches on the outer periphery of the pad (Figure 4) were caused by the

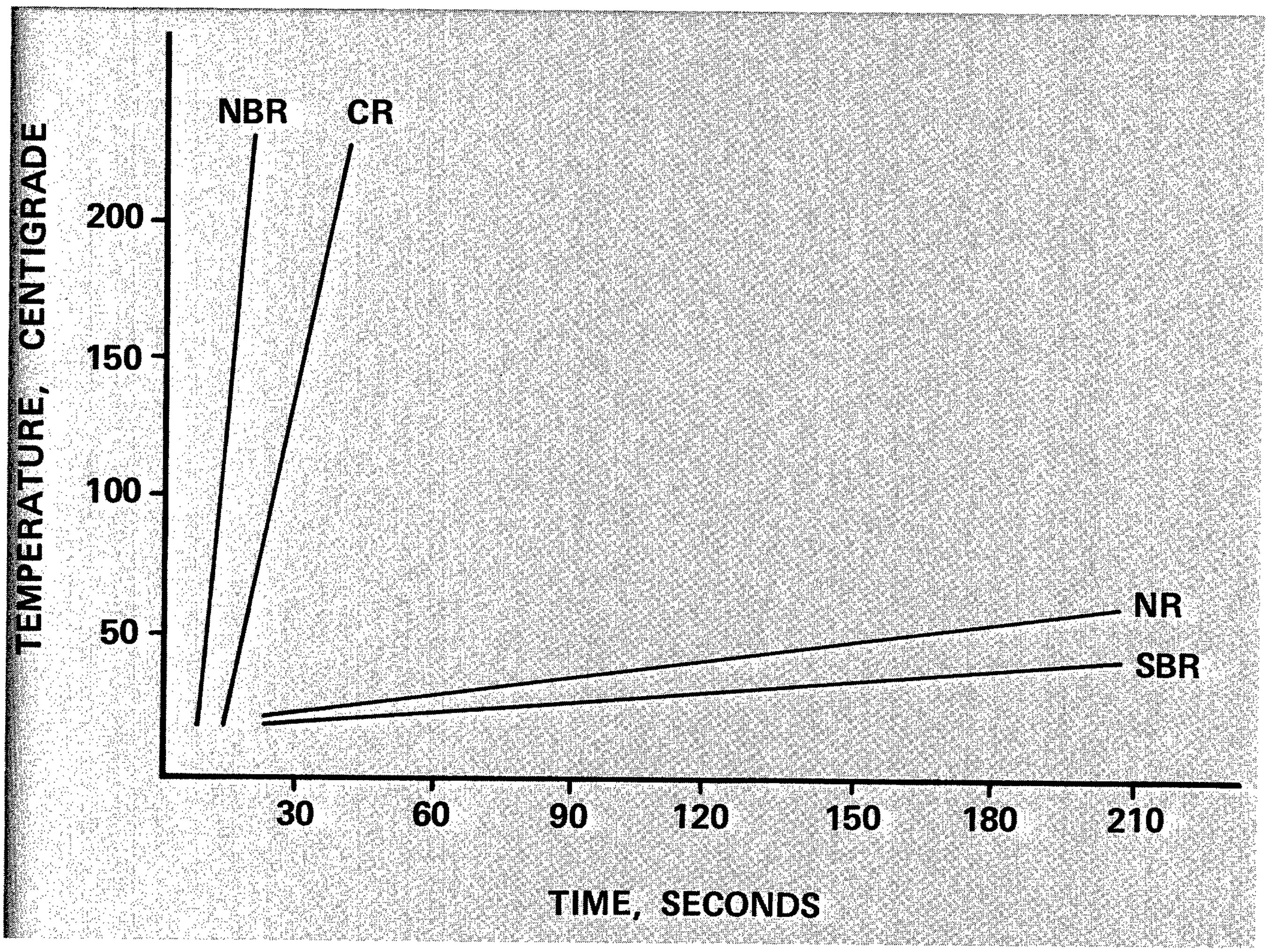


Figure 3

rotating action of a split ring. The field test report indicated that the microwave preheated pad was equal to or better than the field issue pad and would have been serviceable for additional rounds had the test been longer.

Other Uses

While this test work was based primarily on a process for manufacturing obturator pads, this process should be effective for track pads, bogie tires, shock mounts, and other thick sectioned items requiring long curing periods.

Figure 4

KURT VILLHAUER is a Project Engineer currently engaged with development of third generation image intensifier tubes and related components at the Night Vision and Electro-Optics Laboratory, Fort Belvoir, Virginia. He has worked on image intensification projects there for 22 years developing night fighting optical devices. Among his earlier activities were involvement in development of a passive device in the early '60s which produced no source radiation; also, high gain intensification tubes using microchannel plates and not requiring an infrared source. Mr. Villhauer received his Mechanical Engineering degree in 1954 from Long Island Technical College, State University of New York.

Photograph

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Microchannel Plate Quality Control

Total Program Essential

Quality control of the complex fabrication steps required to manufacture microchannel plates for the U.S. Army's electronics equipment has taken a giant step forward with the culmination of a project by Varian Associates for the Electronics Research and Development Command. Now, there are available a Quality Assurance Policy Manual and a Quality Assurance Operating Procedures Manual which can be used to implement a system of quality control for any supplier of Army electronics equipment, regardless of organizational structure or products.

A microchannel plate is a high speed electron multiplier constructed of an array of glass channels. The purpose of this program was to develop, document, and establish a quality control program to improve control of processes and techniques used in the manufacture of 18mm and 25mm microchannel plates.

Undertaken by Varian Associates, Inc. for the U.S. Army Electronics Research and Development Command, the program consisted of two separate but interrelated tasks which were performed concurrently. One task was the generation of the documentation required for the general quality system, while the other task was the detailed documentation required to control the manufacturing processes.

Multiple Step Fabrication Process

The process of producing microchannel plates, or MCP's (Figure 1) begins with single fiber fabrication. Here, a solid glass rod called core glass is inserted into a glass tubing termed clad glass. The inner diameter of the clad glass and the outer diameter of the core glass are very close dimensionally (both ID's approximately 1 inch). The assembly is loaded into a drawing machine which lowers the glass slowly into a hot zone where the glass is melted. During the draw operation, the fiber diameter is continuously measured. Next, single fibers are tacked. Tacked single fabrication consists of cleaning, packing, and sintering single fibers into a hexagonal shape. The tack single process is necessary to bind the single fibers together to perform the multifiber draw process. Multifiber fabrication consists of drawing a tack single into

NOTE: This manufacturing technology project that was conducted by Varian Associates was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DAR—COM. The ERADCOM Point of Contact for more information is Mr. Kurt Villhauer, (703) 664-1725.

multifibers. The tack single is assembled into the draw machine. Quality Assurance inspection consists of measuring the flat-to-flat dimension, channel diameter, and wall thickness. The open area ratio is calculated using the channel diameter and wall thickness measurements. The multifibers are checked for visual characteristics such as shifts, distortion, edge indentations, irregular hole sizes, and irregular web thickness.

Multifibers then are stacked according to the number of multifiber assemblies required for the size of the active area of the finished plate (i.e., 18mm or 25mm). The multifibers are inserted into a glass tubing called "border glass". This assembly is sealed together, then placed in a boule press machine. The boule press machine, by a combination of temperature and pressure, fuses the multifibers together and to the border glass. The assembly after pressing is called a boule.

Boules are then sliced into plates and the plates are edged, lapped, polished, and inspected. The core is then chemically removed from the plates to form the channels. This is followed by hydrogen firing (to reduce lead oxide in the glass), electroding (to produce a hard, electrically conductive surface), and inspection.

Quality Assurance the Key

A quality assurance policy statement was issued which gives the quality assurance organization at Varian the final jurisdiction in all matters involving quality of workmanship and the conformance of products and materials to specifications, drawings, established standards, and contractual requirements. This policy statement also establishes the fact that each individual is responsible for the quality of his specific work and each supervisor is responsible for the quality of all work performed under his direction.

It is Varian's belief that a total quality program is essential to assure the delivery of reliable products. Division functions (engineering manufacturing, material control, marketing, etc.) will have a defined program to assure the quality of work performed within the function. The quality assurance organization will determine that quality programs are in existence and will provide surveillance to assure that they are adequately implemented.

Manuals Revised Variably

Two manuals—a Quality Assurance Policy Manual and a Quality Assurance Operating Procedures Manual—together contain the elements of a quality system required by MIL-Q-9858A. The Quality Assurance Policy Manual contains the basic quality assurance policies required to implement the program. It is intended to be a stable document with infrequent changes.

The Quality Assurance Operating Procedures Manual describes the manner in which the quality assurance policies are implemented. It contains the information for the "who-how-when" required for day-to-day operation; it is intended to be dynamic and will be revised when necessary to update and document existing conditions.

Drawing and Charge Control

At the start of the program, intensive efforts by engineering and quality personnel were made to update existing paper work. This paper system was in accordance with standard procedures. This system is effective for building tubes where many subassemblies are made and brought together in higher level assemblies. However, it was not practical for microchannel plates. Although manufacturing engineering and quality engineering could work with the system, production assemblers and supervision had difficulties with it. The major conflict in the system was that part of the information the assembly personnel needed was contained in processing specifications and work instructions were combined into one specification system called "Standard Process Procedures" which details inspection requirements for microchannel plate inspection. In all probability, the reason the tube system did not work for microchannel plates is because there are no subassemblies which come together for higher level assembly in microchannel plate production.

Process Yield

Tables 1 and 2 contain the yield that can be expected using the equipment fixtures and processes as of October, 1977. The range limits are based on one standard deviation total spread. The process averages are based on performance since June, 1976 from the point when the processes have been stabilized.

A Viable, Cost Effective Appraisal

The quality system generated on this program has proven to be a viable, cost effective approach to product control. It provides a firm base for obtaining process uniformity, for continuing effort to improve the yield in the production line, and for training new employees.

Process uniformity was improved by providing work instructions that are easily understood by the people doing the work and their supervisors. Process documentation sheets were provided for sign-off for each major operation by assembly personnel. These documentation sheets closely follow the Standard Process Procedures and include provisions documenting any conditions observed

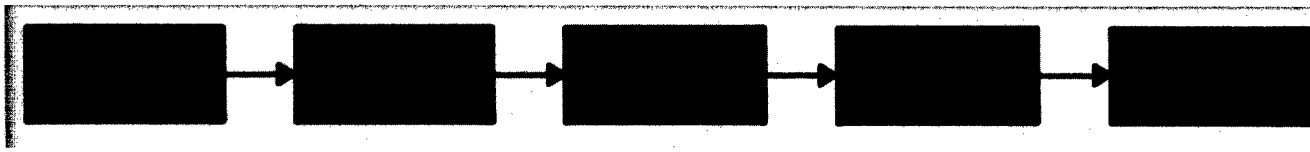

Figure 1

that differ from those normally encountered. Since the work instructions are clear and complete, it has made it easier to administer the task of ensuring that processes are performed as specified.

Management Impressed With Results

Management has gained confidence that the information derived from the quality system is valid. The feedback loop on production problems is short, so that effort can be put into problem areas as they occur. Trends from the data reports are used to establish long term projects for process improvement. For example, a program was implemented to assure that calibrated thermocouples and meters were used for fiber drawing, boule pressing, and hydrogen firing.

The quality system is dynamic due to an effective engineering change control system. Engineering change orders can be reviewed and approved by engineering, manufacturing, and quality within one working day.

Management also has found that the present system is invaluable for aiding new employees at all levels—engineering and assembly workers—in their training. Assembly personnel have been able to perform specific processes very quickly, while engineering personnel have been able to identify the sequences of product flow with a minimum of effort. It also has aided in improving the total knowledge and understanding of long term employees. Quality engineering has become responsible for unbiased transfer of customer requirements to production line acceptance criteria. As a result, material being returned from the customer due to specification interpretation has been reduced to a low level.

Quality engineering reviews the customer's acceptance requirements and has reflected these into internal requirements to assure a high confidence that the product will ultimately meet the customer's end use. This has caused the quality engineer to become intimately involved in day-to-day decisions. In addition, general management has been impressed with the value of the quality system generated during this program to the extent that it is being applied to other product lines within the division. The quality program established during this study has been noted by other large industrial companies and could be incorporated easily into the procedures of other subcontractors with a minimum amount of interface and cost.

Yield by Station 18 mm				
Station Title	Yield, Production Line October, 1977	Yield, Pilot Run	Expected Process Average	Expected Limits, ±%
Plate rounding	86	100	94	5
Plate edge and lapping	89	93	91	3
Plate polishing	99	96	93	6
Plate washing	—	—	—	—
Chemical processing	95	99	95	4
H_2 firing	94	98	96	2
Pre-electroding	71		74	6
Electroding	79	89	88	6
Final electrical test	91	20	65	10
Final QA Inspection includes waivers	82	82	80	6

Table 1

Yield by Station 25 mm				
Station Title	Yield, Production Line October, 1977	Yield, Pilot Run (Boule 1277)	Expected Processing Average	Expected Limits, ±%
Plate rounding	100	100	98	2
Plate edge and lapping	88	92	90	2
Plate polishing	98	98	96	2
Chemical processing	98	100	97	3
H_2 firing	90	100	94	3
Pre-electroding	75	90	81	6
Electroding	74	94	85	4
Final electrical test	48	74	75	10
Final QA inspection	56	78	70	10

Table 2

Corrective Action Easier

The documentation generated on this program provides a firm base for continuing efforts to improve the yield in the production line as well as increasing the acceptance rate at customers' facilities. The process averages in Tables 1 and 2 are representative of present processes, fixtures, and equipment. The averages are by no means optimum, but could be increased. Investigation by engineering to determine the cause of particles at pre-electrode inspection and final inspection has resulted in a program currently in process to upgrade the fixtures at chemical processing as well as change in the method of handling plates. This will eliminate handling by fingers and will prevent damage to the active area. The investigation was initiated in part because of the confidence generated from the Standard Process Procedure system that assembly personnel were performing the processes in accordance with procedure. Therefore, the unacceptable yields were a function of inadequate specifications and/or equipment.

As a result of the present quality assurance procedures, Varian now has the ability to determine the cause of customer complaints and take corrective action.

The Quality Assurance Policy Manual and the Quality Assurance Procedures Manual are similar to those used for equipment, tube, and solid state operations within Varian as well as within other systems companies. The manuals can be used with modifications to suit the particular organizational structure and products of other companies.

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US Army ManTech Journal

Guidelines for Defense Contractors

Volume 8/Number 2/1983

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Contents

ABOUT THE COVER:

The dramatic photograph on the cover of this issue of the U.S. Army ManTech Journal depicts what may be a dying breed of skilled workmen in the Army's industrial base operations. The welder shown is working currently at Rock Island Arsenal on field components, but when the Arsenal's Project REARM is completed in 1987, much of the welding this workman is doing will be done by computer controlled robot devices and automatic welding equipment planned for installation.

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Comments by the Editor

RAYMOND L. FARROW

Several items of high interest to our readers are contained in this issue of the U.S. Army ManTech Journal. Reports on two important guidance conferences highlight the contents of the magazine and point up the fact that the Army's mantech activities are continuing to attract a large number of industrial participants who have responded to our needs for development work in specific areas. The system of conducting these conferences in order to offer Army guidelines on needed manufacturing technology work has been highly successful for all concerned in the past and will continue to be an extremely effective way of attaining Army production goals and efficiencies.

The first of these conferences discussed is the FY85 MM&T Guidance Conference conducted by the U.S. Army Munitions Production Base Modernization Agency last November in Dover, New Jersey. This fifth annual conference was attended by over 125 representatives of private industry as well as 150 Government personnel, who followed the theme "Technology Investment—Key to Industrial Preparedness". This stressed both the need to invest in the development of technology and the need to implement the technology that is developed onto the factory floor. The need for proposals in the area of Army munitions, including large and small caliber, chemical, and product assurance formed the heart of the conference, with some interesting insights into the perspectives of the Air Force and Navy, along with those of MTAG and DARCOM—particularly, the thrust toward industrial productivity improvement, or IPI. MMT opportunities in current production also were discussed by the Army's Rock Island Arsenal representative.

A second important guidance conference is discussed in the article on the U.S. Army Aviation Research and Development Command's Army Aviation Manufacturing Technology Conference III held in Williamsburg 7-11 March of this year. Panels on Metal Airframe, Nonmetal Airframe, Propulsion, Rotor, Drive, and Aircraft Subsystems heard over 170 proposals on manufacturing technology projects emphasizing Propulsion and Subsystems. Over 220 attendees participated in the five day conference, representing 57 industrial firms and 9 Government agencies. Some of the Army's most outstanding mantech accomplishments have resulted from proposals encouraged by these guidance conferences, and advances in coming years certainly will be profoundly affected by these two conferences and those that are forthcoming thru other agencies.

As has become our practice over the past several issues of the U.S. Army ManTech Journal, this issue contains a multitude of brief reports on the status of ongoing projects, each giving the name of the Army project engineer and his telephone number for ease of contact by our readers who may have a special interest in that given topic.

The Tank Infantry Systems Division of the U.S. Army Armament Research and Development Command has completed a project on automated pre-encapsulation inspection of integrated circuits which is highlighted in one article in this issue. Although

such an automated inspection system as yet is unavailable commercially, a thorough survey was made of firms working on systems that might prove feasible. These include image comparison techniques, image understanding, laser optic technologies, acoustic microscopy, and electro-optical pattern recognition. Further work is planned that will make a best buy prediction possible.

Composite dies for high energy rate forming are discussed in an article in this issue on a project done in-house at the U.S. Army Materials and Mechanics Research Center. High temperature alloy and titanium parts for helicopters now can be formed in half the time and for half the cost of other methods used previously.

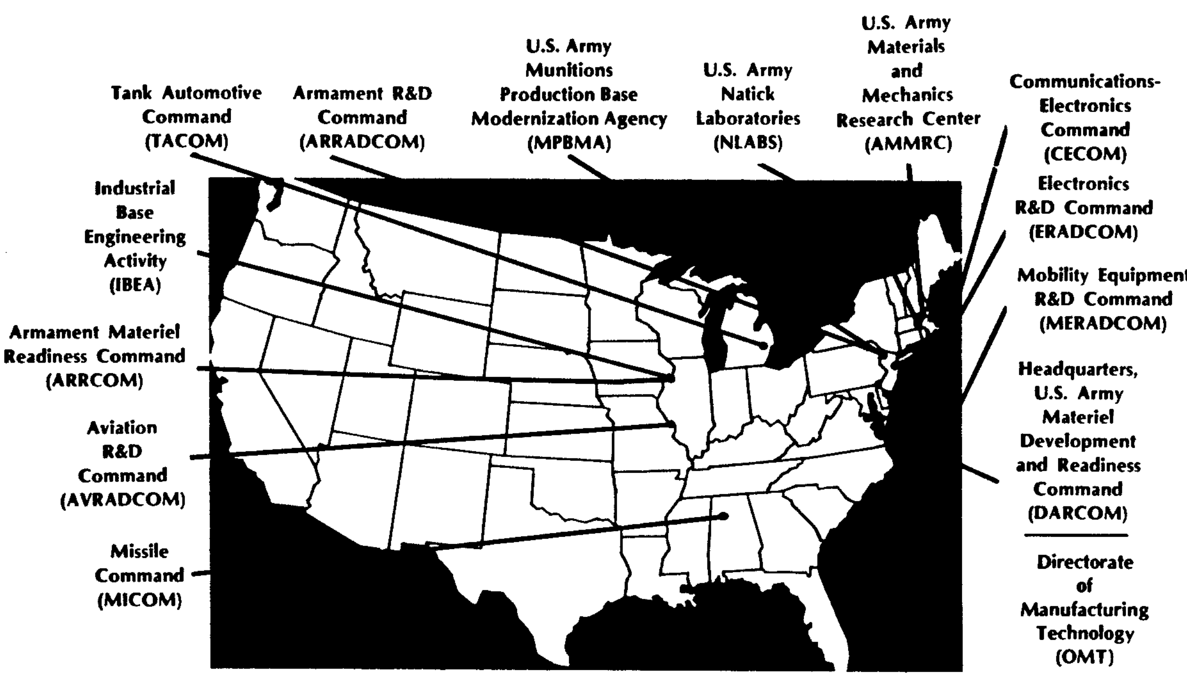
The self cleaning action of normal inertia welding is lost during the welding of rotating bands on projectiles, so this problem was attacked by a project carried out by the Large Caliber Weapon Systems Laboratory of the U.S. Army Armament Research and Development Command. Our article on projectile banding via inertia welding details the results of this successful project, in which the parameters required for cleanliness of surfaces were determined for effective bonding on rotational axes.

Improved visibility and ballistic capability for tanks were achieved by the U.S. Army Tank-Automotive Command during a mantech project on lightweight armored vehicle vision blocks, as described in our article in this issue of the U.S. Army ManTech Journal. The work reviewed the performance and design data required to meet a specified threat level, then new designs of vision block were fabricated and tested which enhanced crew performance in the field.

The applicability of aluminum-steel transition strips formed by explosive bonding in the joining of heavy plates of dissimilar metals has been verified during a mantech project by the U.S. Army Tank-Automotive Command. This Army ManTech Journal article details the procedures that were used to prove this technique feasible for the first time on such heavy components.

Batch processing requirements for fabrication of Nd:YAG laser rods were satisfied by the results of a manufacturing technology project sponsored by the U.S. Army Electronics Research Command; development of the critical tool to accomplish this objective—a polishing fixture—is described in our article. Design and fabrication of this tool has brought the cost of individual Nd:YAG laser rods down to a realistic production value.

DARCOM Manufacturing Methods and Technology Community



5th Annual Conference at Dover

FY 85 Munitions MMT Conference

By

Rex Powell

Munitions Production Base Modernization Agency

The U.S. Army Munitions Production Base Modernization Agency hosted its 5th Annual Manufacturing Methods and Technology (MMT) Guidance Conference at ARRADCOM Headquarters on November 9, 1982. The conference concentrated on technology needs for the FY85 Munitions MMT Program and was attended by 125 representatives of private industry as well as 150 Government personnel.

The theme of the conference was "Technology Investment—Key to Industrial Preparedness", which stressed both the need to invest in the development of technology and the need to implement the technology that is developed onto the factory floor. Results of the conference will mean more extensive industry participation in the MMT program and better planned and executed MMT projects.

Key Points Emphasized

Col. Henry Thayer gave the Welcome and Introductory Remarks, which centered around the Munitions Production Base Modernization program and planning guidance for MMT. This latter topic focused on six key points: support of facilities modernization program, provision of improved processes for existing facilities, evaluation of new processes for future facilities, improvement of project justification/screening and selection, broadening of industry participation in planning, and improvement of program execution and implementation.

MM&T program execution will be improved through the following initiatives:

- Terminate/Complete Old Projects
- Continually Measure Effectiveness
- Weed Out Losers and Accelerate Winners
- Don't Overload Contractor Capability
- Shorten Execution Times

NOTE: This manufacturing technology conference that was conducted by the Munitions Production Base Modernization Agency was funded by the U.S. Army Armament Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MPBMA Point of Contact for more information is Bill Donnelly, (201) 724-2011.

- Validate Benefits at Project Completion
- Reward Quality Performance
- Assure Implementation of Results
- Transfer Technology to Industry/OGA
- Reward Quality Performance.

Col. Thayer closed with a challenge to industry (and everyone) to reduce production costs, reduce facility costs, improve producibility, increase productivity, and improve product quality.

Motivation Increase

A program overview of facility modernization and expansion delivered by Mr. Charles Osiecki centered on the TOA Overview, program thrusts, other service support, and the FY84 and FY85 plans.

The DARCOM perspective for industrial productivity improvement (IPI) by Mr. Charles Kimsey proposed a strategy to reduce acquisition costs by increasing contractor motivation to maximize manufacturing efficiency. The objective of the IPI program is to increase profits to contractors (with performance incentives, for example) while reducing cost to the Government. Specific programs involving such companies as General Dynamics and Avco Lycoming were reviewed.

The MTAG perspective by Mr. John Kaschak discussed its mission, structure, responsibilities, and involvement with industrial associations and societies.

PROCESS OPPORTUNITIES AND IMPLICATIONS

U.S. Army

The Army's major **large caliber** munition R&D thrusts as discussed by B. W. Busheyare to defeat armor, counter battery fire, and interrupt movement and deployment of troops and armor. The principal munition systems are (1) tank fired kinetic and chemical energy projectiles, (2) artillery delivered precision or "smart" projectiles for counter battery fire and the defeat of armor, and (3) ground emplaced artillery or air delivered antipersonnel and antitank mines to inhibit movement of troops and armor in both forward and rear areas of engagement.

In **small caliber** munitions, the emphasis is on increased penetration of helmets through the addition of steel penetrators to the conventional ball bullet and caseless amunition wherein the propellant is molded around the projectile. Although not a new concept, new binder materials have been developed to overcome the cook-off and other problems that previously prevented the successful development of caseless ammunition. Other areas of emphasis are on plastic bank ammunition for the .50 caliber weapon and on low cost, limited range training ammunition for cannon caliber weapon systems. High-length-to-diameter kinetic energy penetrators are being designed and fielded for .50 caliber through 30 mm weapon systems. also, multipurpose fuzeless, armor penetrating high explosive projectiles for these weapon systems are under development. In these projectiles, the explosive charge is sensitized upon firing to respond to a shock and/or heat stimuls for initiation upon penetration of the target. The last small caliber item is a Command Adjusted Trajectory (CAT) projectile for application in the air defense role. The projectile upon firing is tracked by the firing crew or another command crew which sends commands to the onboard projectile control system to modify the trajectory to intercept the target. This project is in the prototype design phase. Each of these small caliber programs has definite manufacturing technology needs; however, the emphasis of this presentation was on large caliber munitions.

Small caliber munitions were further discussed by Mr. William Dietrich. Near term requirements are for a 25 mm long rod penetration, .50 caliber robot launched AP projectiles (SLAP), .50 caliber plastic blanks, .50/5.56 caliber short range training ammunition, plastic links, and plastic packaging. Also discussed were improvements of existing facilities and future implementation of programs (e.g., maneuvering projectiles and caseless weapons systems).

Chemical munitions was presented by Mr. T. J. Abbott of the Chemical Systems Laboratory. This laboratory is responsible primarily for deterrent agent and munitions systems and the smoke screen agents and munitions systems. As far as MMT programs are concerned, there is a need to prove out new and/or improved manufacturing, handling, and load, assemble, and pack techniques.

In the deterrent area, lethal binary chemical munitions have a high visibility within the DOD. Work is centering around a VX munition along with a treatment process to handle waste by-products which will result from these facilities.

Product assurance by Mr. Gus Sylvestro discussed PAD responsibility in inspection technology, status of some of the current PAD MMT programs, planned PAD MMT programs, and principle MMT testing needs.

PAD responsibility in inspection technology centers on development, coordinatioin and management of overall ARRADCOM program in inspection technology. They provide the single point of contact for all product assurance considerations to MPBMA and also manage and provide Level II chairmanship for ARRADCOM materiel testing technology (MTT) programs. In addition, they provide test technology in the following areas of specialization: ultra-

sonics, optics, radiology, radar, eddy current, magnetic particle, magnetic flux leakage, image processing, and propulsion.

Principle MMT needs are for:
- Modernization of closed bomb laboratory at RAAP
- NDT inspection of combustible cartridges
  Case for 120 MM tank system
  Increment containers for 60/81 MM mortar
- Reliable and cost effective test for acceptance of primers
- A digital image amplification X-ray system for inspection of mortar rounds
- Automated inspection of small arms cartridge links
- Acceptance of stick propellant produced on an automated line
- Base separation and void measurement by microwaves
- Improved data acquisition and ballistic tracking of SMART projectiles
- Automated pre-cap visual test
- Nondestructive testing of electrical connections.

PAD MMT programs for FY85 will provide reliability, safety, and cost effectiveness by exploiting the following technologies and automation techniques:
- Real-time image amplification radiographic system incorporating automated digital signal processing techniques
- Automated image processing system to eliminate human judgment in interpretation of visual defects
- Swept frequency radar to detect voids and base separation in cast high explosive fillers
- Thermal wave analysis to determine bond strengths.

U.S. Air Force

J. Reginald Lewis of the Armament Division discussed the Air Force munitions R&D thrusts. Their current product line includes small caliber ammo and guns, support equipment, aerial targets, cluster weapons, guidance kits—TV, IR, laser, air-to-air missiles, and surface attack weapons. Examples of advanced and full scale development efforts and exploratory and advanced development efforts were given. Requested future manufacturing technology projects include advanced broadband radomes, 30 MM APFSDS projectile and sabot diverter, 30 MM augmented lateral effects projectile, RAUFOSS technology ammunition, solid state accelerometer, seeker gyro and inertial reference unit, tactical ring laser gyro, WASP injection molded electronic enclosures, thermal battery production improvement, and cast bulkheads/Tailcone—TMD.

Mr. Harvey Burnsteel discussed the Navy's ammunition activities, which presently feature participation in several programs with the Army which are discussed in that service's presentation.

CURRENT PRODUCTION MMT OPPORTUNITIES

Mr. Dennis Dunlap (ARRCOM-RIA) began his presentation on MMT opportunities with ongoing production with some areas in general program management which need to be improved upon. To improve program visibility, our implementation record, technical reports, end of project presentations, MMT accomplishment charts, and auditable benefits must be improved. Improving productivity was also discussed in relation to indirect labor, test/inspection methods, direct labor, and robotics, CAD/CAM.

One key point to remember is that our production base procedures must be involved from the beginning.

Proposals have been received from GOCO facilities in four areas—(1) metal parts; (2) propellants and explosives; (3) load, assemble, and pack; and (4) environmental protection. They have been forwarded for consideration of MMT funding **Metal parts include** pre-impregnated fiberglass for M483 MPTS, torque and centralizing assembly machine, application of industrial robots in MPTS operations, warm shearing of billets, automatic inspection for rotating band chemistry, automatic tool wear compensation, automatic inspection for fiberglass content, and automatic inspection of M42/M46 grenade bodies.

Propellants and Explosives include pilot plant for NC components, automatic attrition mills for pulping houses, improved laboratory analysis techniques, nitroguanidine production process optimization, screw extrusion of solventless propellant, and use of crude RDX/class in composition B.

Load, assemble, and pack center around improved sewing systems and automatic printing for bag manufacturing, vibratory loading system for propellant charges, digital checkweigh scale, improved loading of base ignited charges, application of industrial robots in LAP operations, automatic indexing and pouring machine for melt/cast explosives, M483 LAP improvements, electrical tester for RAAM lenses, automatic marking of wirebound boxes, and automatic inspection of M42/M46 grenades.

Environmental protection encompasses feasibility of filtering GN reactor effluent, treatment of mechanical roll waste water, diethylphtalate (DEP) decomposition, cyanide removal from waste calcium carbide, treatment/disposal of contaminated sludge, improved pollution monitoring in wastewater streams, and improved treatment processes for wastewater streams.

Some current MMT needs include prototype 50 caliber linking equipment, improved 50 caliber bullet manufacturing, improved process for 7.62 MM manufacturing 16 inch propellant charge loading improvements, automated process for FASCAM, NDT of RAP delay column assemblies, improved process for primer mix nitration, and pretreatment reduction of pink water RDX content.

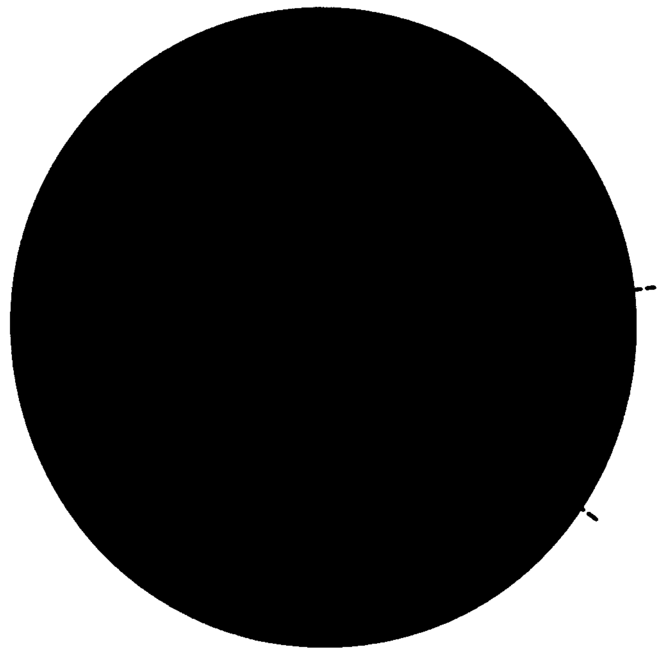


Figure 2

Where the Dollars Will Be Spent

Project proposal requirements, program schedule, and thrusts were presented by Mr. Rex Powell MPBMA. As can be seen in Figure 1, the MMT program was at its highest funding level in FY76 and since has dropped considerably. However, funding is projected to rise by FY85 and surpass the FY76 peak. The FY70-83 funding of $377 million (Figure 2) shows that about the same percentage of the available funding has and will be spent in the same technical areas during the FY82-84 period (Figure 3).

The MMT thrusts in products will focus upon seekers and sensors, electro/optical, RDF/high technology division munitions, insensitive explosives/propellants (stick/combustible case and PBX's and RDX/HMX), fuzing—that is compatibility with auto firing, product improved munitions (PIP's), critical materials/substitution, kill mechanisms (SFF, liners, penetrators), microinitiation/detonation, chemical munitions, gun hardened microelectronics, and mobilization/surge/sustainability policy.

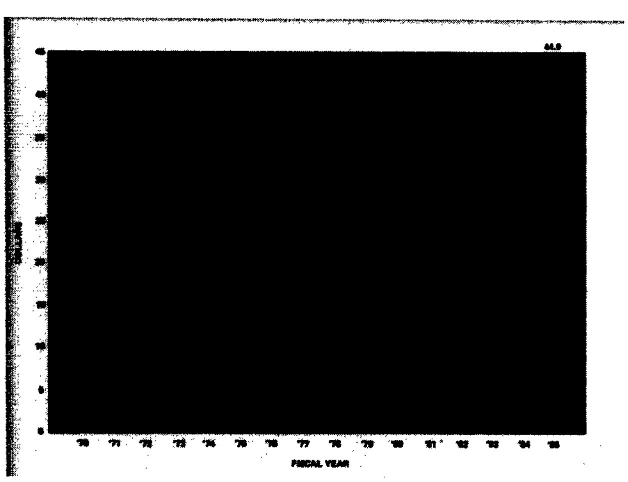


Figure 1

Concerning process equipment, the important areas will be flexible machining robotics, microprocessors and software, advanced assembly and joining technology, automated fabrication and inspection, microelectronics and miniaturization, and composites/plastics), nondestructive testing, advanced metal forming, joining and cutting, optical recognition (fiber optics/lasers), CAD/CAM-computer integrated manufacturing, automated batch processes multiproduct production, industrial modernization incentives programs, regulatory compliance technology, and unit processes (drying and separation).

A summary proposal format to use with MM&T programs also was suggested. It included seventeen key points to consider, ranging from the proposal identification code through the statement of the problem, the proposed solution, facilities, and funding.

What's Needed

METAL PARTS

Mr. Kal Kolis discussed what areas need to be studied in conjunction with the Metal Parts Division. For **tanks,** current items are bare extrusion of billets (DU), ion

vapor deposition for DU cores, improved heat treat technology, and chip recycling/waste disposal. For **artillery,** activity will center on adaptation to existing machines, machine tool monitoring and changing, automated inspection for rotating band chemistry, and automated inspection for fiberglass content.

Cannon's (20 mm to 40 mm) will require high volume, low cost manufacture of ogive assemblies, manufacture of sabots and fins for high L/D APDS projectiles, process to assemble fuzes to projectiles, and high speed assembly of impact switches.

The **mechanical thrust** will be aimed at manufacturing technology for self-forging fragment liners, cost effective assembly of base to projectile, high speed test of self forging fragment liners, and automated assembly of parachute devices.

Electronics has a wish list broken down into three areas: manufacturing processes, automated assembly, and automatic testing. **Manufacturing processes** include low noise, high gain bandwidth transistors, gunn, mixer and varactor 35 GHz diodes, photolithography—MMW circuit boards, and leaded chip carriers. **Automated assembly** encompasses MMIC IF pre-amp/amp (integrated chip), MMW components on MMIC circuit boards, IR focal plane detectors and transducers, and electronic modules and sensors.

Finally, **automatic testing** includes MMIC subassemblies with RF sensor systems, microprocessor chips, IR transducers, and boresighting—IR focal plane to MMW antennas.

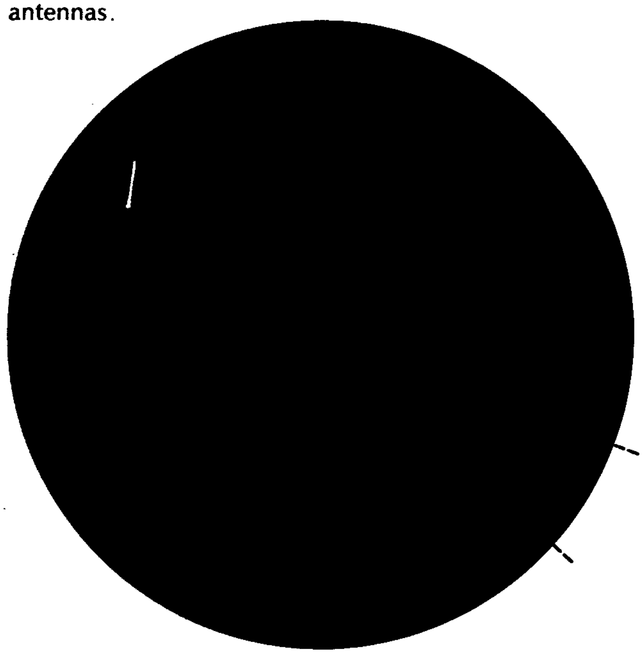


Figure 3

PROPELLANTS AND EXPLOSIVES

Suggested MMT efforts for propellants and explosives were presented by L. Laibson, T. Caggiano, and R. Koppenaal. Areas of interest dealing with wastewater include the pilot plant evaluation for treating detonator wastewater at Kansas AAP, solar aquaculture wastewater treatment, ball powder wastewater abatement, nitroguanidine wastewater treatment, and nitramine propellant wastewaters abatement. Other areas are improved boiler efficiency, air pollution abatement for coat and glaze operations at Badger AAP, manufacture of ultrafine nitroguanidine, process analysis of ROX/HMX slurry, improved manufacturing processes for HMX and EAK explosives, and improved controls for TNT lines—just to name a few.

LOAD, ASSEMBLE AND PACK

Opportunities targeted for load, assemble, and pack by A. Siklosi, D. Muller, P. Corradi, and F. Miksis included plastic bonded explosives (PBX), LAP of 120 mm tank ammunition, cost effective safety, LAP of 75 mm ammunition, improved process technology for chemical munitions, and M483 explosive charge loading improvement.

More Details Available

It is impossible to fully cover all the topics discussed at the FY85 MM&T Munitions Production Base Guidance Conference and the specific needs of the various MPBMA divisions. For example, the Metal Parts Division alone lists over 40 pages of needed future MM&T effort. Included in these listings are program title, funding period, specific technology, related/prior MMT effort, and point of contact.

If your firm is interested in participating in the Army's munitions effort, it is strongly suggested that you obtain a copy of the Conference Proceedings to see where your capabilities fit in. Copies are available from:

The Department of the Army
U.S. Army Munitions Production Base
Modernization Agency
Dover, New Jersey 07801

Less Parts Not Always Cheaper

Army Aviation III Conference Report

By

Bruce Park
Project Engineer

U. S. Army Aviation Research
and Development Command

More than 220 attendees from 9 government agencies and 57 industrial firms participated in the U.S. Army Aviation Research and Development Command's Manufacturing Technology Conference III at Williamsburg, Virginia March 7-11. The meeting at which over 170 proposals were presented by participants, served as an interface between helicopter representatives from all three military services and industry.

Propulsion Leads Categories

A breakdown of proposals for each category follows, with the most highly judged one(s) from each panel to be selected for consideration for funding at a later date.

Airframe, metal	27	Chairman: Allen C. Haggerty
Airframe, nonmetal	33	Chairman: James J. Kenna
Drive	15	Chairman: Alan H. Smith
Propulsion	49	Chairman: Frank E. Pickering
Rotor	15	Chairman: Peter C. Ogle
Subsystem	42	Chairman: Reginald Waller
Total	181	

The total above is greater than the total number of proposals due to the fact that some were presented to more than one panel.

Full Professional Support Given

Conference support was provided by the Hampton Roads Chapter of the American Helicopter Society and the Applied Technology Laboratory at Ft. Eustis, Virginia. The conference sponsor was the American Helicopter Society, Richard Stoessner, President. Actual conference support was provided by the Applied Technology Laboratory, with Jim Waller and Bob Powell serving as points of contact.

Production Engineering Early

The Keynote Address during the opening session was given by General Donald Keith, DARCOM Commander.

NOTE: This manufacturing technology conference that was conducted by the American Helicopter Society was funded by the U.S. Army Aviation Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AVRADCOM Point of Contact for more information is Robert Vollmer, (314) 263-1625.

The synopsis of General Keith's address was to challenge the audience to accomplish the transition of programs from the research and development stage to production in a more efficient and cost effective manner. General Keith stated that there have been disappointments in achieving this objective from both industry and government due to higher priorities. To solve this problem, General Keith stated that both government/industry engineers will be brought into the acquisition process early and will stay throughout development. Adequate amounts of PEP and MM&T money will be obtained to make sure this objective is achieved.

Number of Components A Cost Factor

Mr. Ralph Alex, Ralph P. Alex and Associates, presented the luncheon address. Mr. Alex traced the evolution of the helicopter and noted than many of the MANTECH responsibilities of today were handled immediately on the shop floor using any materials and tools which were available. Mr. Alex also stated that less helicopter components in a helicopter system is not necessarily good. Costs for helicopter systems are minimized when there is a moderate number of components in a helicopter. Helicopter costs rise as the number of components are increased to a very large number or decreased to a small number.

Secretary of Defense Support

Mr. John Mittino, Assistant Under Secretary of Defense for Production, discussed government funding and support for the MM&T and IPI programs. Mr. Mittino stated that at the Office of the Secretary of Defense level there is strong support for these programs. Efforts in Congress are being made by his office to assure adequate funding. This effort continues in lieu of an FY83 funding cut in the Army MM&T program.

Top Proposals Considered

Titles of outstanding proposals from each panel (not in any order of significance) include the following:

Airframe, metal:
- Isostatic Forging of AH-64 Shock Strut
- Powdered Metal Parts
- Improved Low Cost: Superplastic Formed Titanium Structures
- Aluminum Powdered Metal Forgings & Extrusions
- Sheet Metal Work Center
- Group Technology for Sheet Metal Fabrication
- High Integrity Hot Isostatic Pressure Cast Aluminum Parts

Airframe, nonmetal:
- Assembly Level Joining of Large Composite Structures
- Thin Composite Laminate Cutting Methods
- Fiber Reinforced Thermoplastic Structures
- Vacuum Impregnation of Large Co-Cured Composite AF Structure
- Advanced Thermoplastic Composite

Drive:
- Production Fabrication of Overrunning Clutch Spring
- Corrosion Resistant Helicopter Structures
- Ballistic Tolerant Helicopter Bearings
- Laser Hardening of Heavily Loaded Gears
- Powdered Metal Gear Steels

Propulsion:
- Unmanned Machining Cell
- Real Time Statistical Process Control for N/C
- Microwave Frequency Eddy Current Crack Detection
- Improved Coating for Turbine Wheels Using AEP
- Resistant Spot Welding Adaptive Control

Rotor:
- Simplified Tail Blade Fabrication
- Composite Hub Production
- Automated Main Rotor Blade Tracking
- Advanced Composite Rotor Hub CH-47D
- Single Curve Cycle Tail Rotor Blade

Subsystem:
- Automated High Volume Inspection Station
- Automatic in Process Fault Isolation for Digital Hybrids
- Laser Soldering of Printed Wiring Boards
- Low Cost Design and Production of Millimeter Wave Components
- Hand Held Automatic Power Crimper

These proposals are being evaluated, and selection of those considered for future funding will be announced in the near future. Contractors who presented the proposals are not identified.

Automated Pre-Cap IC Inspection

Could Other Methods Do the Job?

A recently completed study by Columbia Research Corporation for the U.S. Army Armament Research and Development Command's Tank Infantry Systems Division was aimed at examining the feasibility of an automated inspection which can perform a 100 percent internal visual inspection of integrated circuits during production. The importance of such a system is realized when one becomes aware that scatterable mines, such as the remote anti-armor mine (RAAM) and the modular pack mine system (MOPMS), use large scale integrated circuits in their electronic fuzes.

The 100 percent visual inspection prior to encapsulation (pre-cap) is necessary for safety reasons, and it also would eliminate the use of microscopic examination and the subjectivity of human error.

The Current Technology

Of thirteen large companies who currently make integrated circuit components for such purposes, none uses an automated system. They perform either a destructive visual inspection on a sample basis or use microscopic examination. About two years ago, experiments with a video system were conducted by one company; it was found to be very useful for training and for group viewing on marginal decisions; however, it did not improve the inspection process sufficiently to justify its cost and therefore was discontinued.

Engineering Studies and Evaluation

To allow a more comprehensive and objective evaluation of the alternative inspection procedures and of the positions taken by the various commercial vendors, Columbia conducted engineering studies of the specific requirements of Test Method 2010.4. This included an in-depth investigation of the requirements and implications of visual inspection as defined by MIL-STD-883B along with a comparison with the requirements of MIL-M-38510 for military JAN microcircuits.

For example, MIL-STD-883B (Method 2010.4) requires inspection of microcircuits under optical magnifications as indicated. There are 15 different types of defects each with descriptions of the accept or reject criteria: thin film resistor contact area, dielectric isolation defects, balling of die attach material, beam lead die faults, beam lead bond area and location, bonds at metallization exit, bond dimensions, bonding pad area, passivation and diffusion

GARY NIEMIC is a Project Engineer at the U. S. Army Armament, Munitions, and Chemical Command (AMCCOM – formerly ARRADCOM) at Dover, N. J. There he has been actively involved with the design, development, and evaluation of test instrumentation used on various armament systems while assigned to the Instrumentation Engineering Branch of the Product Assurance Directorate. Systems he has acquired experience on include mines, missiles, and large and small caliber ammunition.He has worked at Dover for the past six years after receiving his B.S.E.E. in Biomedical Instrumentation and his M.S.E.E. in Computer Systems from New Jersey Institute of Technology.

NOTE: This manufacturing technology project that was conducted by Columbia Research Corporation was funded by the U.S. Army Armament Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Gary Niemic, (201) 724-5603.

faults, MOS gate alignment, MOS scratches and voids, scribing and die defects (cracks), termination ends, scratches, and voids.

The inspector must scan the enlarged (magnified) chip image looking for flaws or defects. This scanning process is an orderly one which proceeds, for instance, from left to right and top to bottom, looking across some imaginary row and at each imaginary column within each row. At each stopping point of the visual scan the inspector must make a series of discriminations. These are shown in Figure 1.

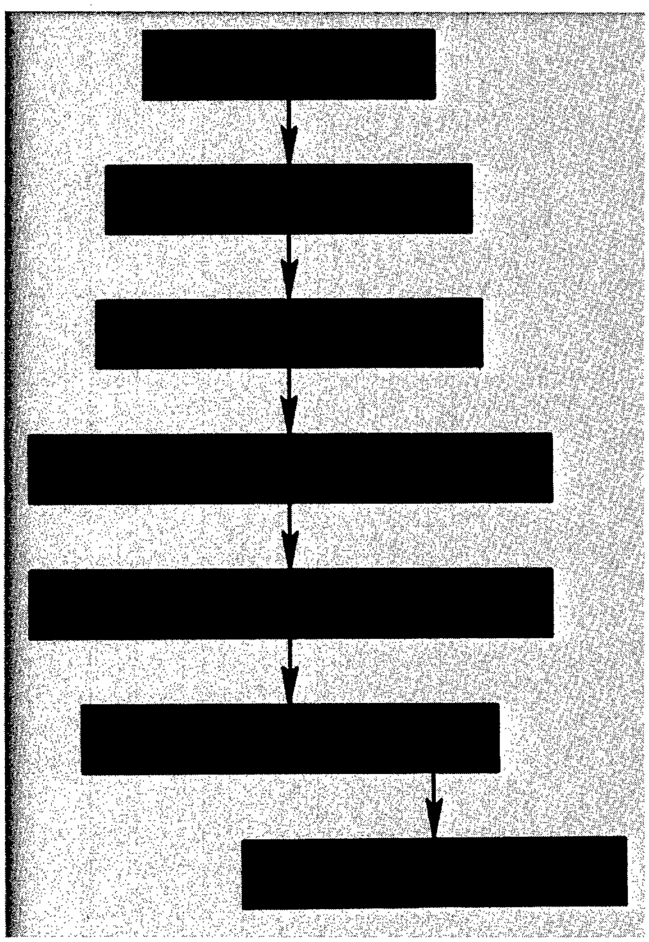


Figure 1

Human Factors Important

Studies have been conducted in the area of how many discriminations a human can make in a given period of time. The conclusions are that one can make from 10 to 20 mental discriminations per second. These are cognitive processes related to the perception of retention of simple stimuli such as those listed in Figure 1. The variance is a function of fatigue. At the rate of 20 discriminations per second, the operator tires very rapidly. It has been concluded that an effective sustained rate of 18 discriminations per second is reasonable and quite achievable in practice, with breaks for relaxation. A trained inspector could inspect one chip every 3 minutes, in accordance with MIL-STD-883B, Method 2010.4. This does not, however, account for the time required to position and repeatedly reposition the chip in the field of view of the microscope.

Another factor which must be considered when evaluating the human visual inspection is that not all of the defects are going to be detected. Two operators examining the same chip will detect different defects. Even the same operator looking at the same chip on two different occasions often will record different findings.

Current Instruments and Systems

MICROSCOPES

Several microscope systems currently available were investigated. Each has accessories available to tailor it to specific applications. Three of these special features would seem to be particularly useful in performing the pre-cap visual inspection:

- **Nomarski Differential Interference Contrast (DIC).** Nomarski DIC is a specialized illumination attachment available on some of the microscope systems. This attachment highlights slight variations in surface quality. It does this by utilizing differences in grey color density or in interference colors. In this manner, the Nomarski DIC can indicate scratch depths and peak-to-peak heights.

- **Video Compatibility.** Some of the microscopes already are compatible with closed circuit television (CCTV). Others have phototubes for camera attachments and could conceivably be adapted for CCTV use. A trinocular arrangement allows for simultaneous CCTV and binocular viewing, with the majority of the light being fed to the video monitor.

- **Automatic Transporters and Sorting Systems.** Two inspection stations, the CI-750 by Applied Materials and the Series 3000-I by Adcotech, automatically transport the ICs to and from the station. In the CI-750, this is accomplished by means of belts, while in the Series 3000-I, the ICs are tube fed. In both systems the operator indicates whether to accept, rework, or reject an IC. The sorting is then performed automatically and the information is stored in the system memory for later recall. The potential for damage to the ICs diminishes as the amount of handling decreases. The Applied Materials CI-750 is compatible with the Olympus microscope while the Adcotech Series 3000-I is video compatible.

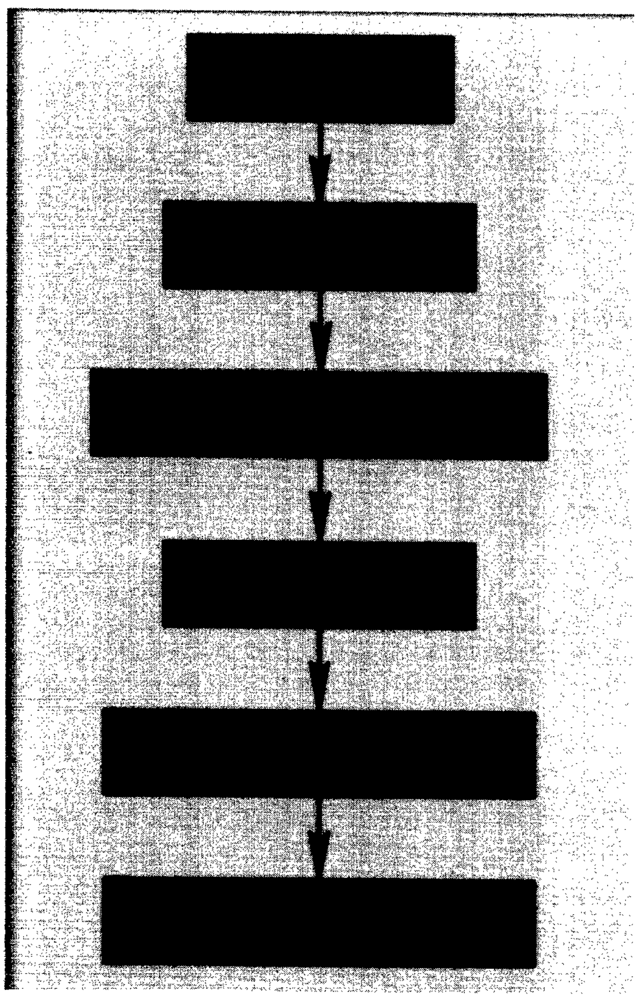


Figure 2

VIDEO SYSTEMS

Available video systems range in sophistication from simple CCTV equipment mounted on microscopes to image analyzers that can map dust particles on semiconductor chips. Video systems are employed at many stages of production to inspect raw materials, wafers, devices, circuit boards, and finished products. The technology has added accuracy and speed to both complex and simple inspection routines in many areas.

Several microscope manufacturers offer photomicrographic video equipment as options for their products. In the simplest arrangement, a TV camera is mounted on a trinocular microscope, and a video monitor is used to display the magnified image. The unit under test is thus magnified by the microscope lens and enlarged by the video system. Such systems are useful to reduce eyestrain or to allow more than one person to observe the unit under test. Multiple monitor hookups can also be arranged to carry the image to other locations. Instrumentation of this sort facilitates inspection in cases where low volumes do not demand automated techniques or where the object does not lend itself to inspection by any other method.

The TV systems' enlargement or magnification is a function of the camera's picture tube diameter and the diagonal dimension of the monitor. This factoris multiplied by the microscope magnification to obtain the total magnification. For example, a 1 inch camera tube, 13 inch monitor, and a 40X microscope objective yield a total screen magnification of 832X. A setup that provides such power can aid an inspector in making basic accept or reject decisions. For instance, shapes of incoming devices may be checked by comparing the video image of the sample with a Mylar overlay affixed to the monitor. Deviations from the standard drawn on the Mylar are readily apparent for noncomplex items, and the inspector can make a go or no-go judgment. If measurements are necessary, microscope manufacturers offer a variety of stage micrometers and reticles.

Video Comparators Strengthen Analysis

Just as video technology has enhanced microscope inspection techniques, optical comparators have been transformed into video comprators by the addition of two cameras and a monitor. While most optical comparators require special room illumination or an overhead canopy for a clear view of the projected image, video based systems are freed from these constraints. Alternate images of the sample and the standard may be flashed on the monitor and errors show up as differences in color or

motion between the views. Based on these differences, the inspector can assess the sample as good or bad. For closer inspection, both images can be displayed on a split or overlaid screen. Such instruments are in use inspecting high density printed circuit boards used in computer and aerospace equipment.

In addition to the simplified closed loop video systems as described above, there are various methods of processing the video signal prior to display in order to enhance the image or evaluate its characteristics. Analog video signals from the camera tube can be converted to digital data that may be stored in computer memory or mass storage devices or manipulated and conditioned stored in a number of ways to enhance clarity, identify perturbations, and signal existence of deformities. Such image analysis instruments have generally been employed in fields outside the electronic industry, such as material sciences for counting asbestos fibers and examining petrochemicals and biomedical applications for ascertaining structure and character of cell tissue. There have been limited applications of image analyzers by semiconductor manufacturers for checking direct photolithography and particle contamination of wafers.

AUTOMATED INSPECTION SYSTEMS

Manufacturers of automated test equipment (ATE) were contacted to see if they currently had or were developing an automated system to perform the pre-cap visual inspection. To date, however, no one has such a system available on the market. Details about these systems are difficult to obtain because they are still in the development stage and much of the information is proprietary. However, the following was learned.

KLA Instrument Corporation of Santa Clara, California currently is working on an IC inspection system. This sytem apparently utilizes image comparison techniques between the test chip and a master reference chip. The difficulty with developing such an inspection system is that the requirements of Method 2010.4 push the state of the art in software capabilities. It is one thing to design a system that can automatically perform the inspection. It is another to design one that is cost effective. At present, KLA is using a general purpose computer which is not fast enough to show large decreases in inspection times, although it is still faster than human inspectors. KLA hopes to improve this by custom making the computer to better serve the system. The development process has not yet reached the point where there is any printed information ready for release.

In Japan, Hitachi is reportedly working on an automated visual inspection system for ICs. No details are available about the system other than that Hitachi estimates that it will be about two years before its system will be ready to market.

Contrex, Inc., of Burlington, Massachusetts, has been developing a fully automated chip inspection system (CIS) which utilizes a technique called image understanding. Image understanding can be thought of as the capability of a computer to extract, process, and interpret, in real time, visual information provided by an image acquisition device such as a CCTV camera. The CIS is made up of the following design elements:

- **System controller,** with custom software for chip inspection, error reporting, and tabulation.
- **Image analyzer,** which converts the viewed image into a digitized form, extracting the features needed in the decision making process.
- **Operator console,** which allows manual entry of data and manipulation of the various electromechanical components of the system. The console also includes a videomonitor for reviewing the progress of the tests and for operator prompting.
- **Optical microscope,** with computer controlled Z-axis movement for automatic focusing.
- **An X, Y, Theta positioning stage,** allowing reproducible positioning of the chip under test to 0.0001 inch. This positioner is also controlled by the system controller via the imaging feedback loop.
- **Computer controllable illumination system,** which allows the system controller to maintain a constant level of illumination over the span of the test. It also enables the system to reproduce the level of illumination from one test run to a new test run some period of time later without requiring manual intervention.

LASER OPTICS

Several companies are working on automated systems for the visual inspection of printed circuit boards. In these efforts, laser technology has proven to be a useful tool.

Chrysler Electronics Division in Huntsville, Alabama has developed the LIS-510 inspection system which uti-

lizes a low power helium-neon laser, an X-Y moving iron galvanometer scanner, and several folding mirrors. By scanning over a preprogrammed path, the system produces unique shadow signatures which are picked up by silicon photodiodes. These signals are evaluated by a minicomputer which also controls the scan pattern.

The LIS-510 system is capable of automatically detecting missing components, incorrect lead clinch direction, and improper lead length (long and short). With the use of a reflective glint screen, solder bridges can also be detected. This system is better than 99 percent effective in detecting board faults on the Chrysler production line. It can inspect a 400-lead board for component presence and proper lead dress in less than 5 seconds. It can scan a bare board for improperly sized or placed component holes at a minimum rate of 50 holes per second.

Altman Associates, Stamford, Connecticut, has developed a board verifier system which also analyzes reflected laser beams from the test board to check hole sizes and positions. However, this system does not utilize a master patter stored in its memory. In its place, a second beam from the laser scans artwork that describes the nominal tolerances of the board. The minicomputer then decides if the features of the test board come within the allowed tolerances. This system allows the inspection of different board types without reprogramming. The predicted inspection rate is up to 50 square feet of bare board per minute with measurement accuracies to within 1 mil.

The Inspection System by the **Advanced Control Products Division of Cooper Industries** in Irvine, California is predicted to take about one minute to inspect a bare board for line widths and spacing, line breaks, excess copper, and voids. The system will also detect incomplete pads, poor pad-lead connections, and shorts in ground planes. The inspection utilizes reflected laser beams in analyzing these board features, but its only reference is a set of design rules programmed into its minicomputer. When a violation is detected, the system will either print out the coordinates of the defect or stop scanning so an operater can examine the defect. The use of general design principles instead of master pattern of artwork references eliminates the need for precise orientation of the test board. This system is still in the development stage.

Also in the development stage is a unique solder joint inspection system from **Vanzetti Infrared and Computer Systems** in Canto, Massachusetts. This system utilizes infrared rather than visible light detectors. The laser delivers low power pulses to each joint, heating it a few degrees above the temperature of the room. The minicomputer then compares the joint's thermal response and makes a pass or fail decision. For example, a joint with insufficient solder or a subsurface void will warm up faster and reach a higher peak temperature than will a good joint. Thus, this system can pinpoint faults that a human inspector would be unable to detect.

However, none of these systems in their present forms is capable of performing the pre-cap visual inspection described in Method 2010.4; the pre-cap inspection is too complex and the ICs are too small. However, lasers are capable of very high resolution and pinpoint accuracy. It may simply be a matter of thinking of the inspection problem in terms of lasers.

ACOUSTIC MICROSCOPY

Another useful tool is the acoustic microscope, which allows an inspector to see minute structural details of an object by displaying the object's response to ultrasonic waves. Unlike optical microscopes, they are capable of probing beneath the visible surface. The acoustic microscope displays the changes in the efficiency with which sound is generated in or propagated through the item being inspected. The physical properties of the object such as density, viscoelastic moduli, and thermoelastic coefficients determine the sonic speed, disperson, and refraction of the sound waves. Thus, when reflected or transmitted sound waves are enlarged and displayed, an accurate picture of the target is produced. This display will include those portions of the item which are optically opaque, allowing the inspector to see within or beyond these areas. The system consists of two basic parts. One exposes the object to the ultrasonic radiation and the other senses and displays the resulting acoustic fields. The acoustic microscopes investigated differ in the manner in which they expose the inspected object to the ultrasonic radiation. The image conversion and image display systems are very similar to each other and are widely used in many other imaging systems.

In each acoustic microscope examined, an image display system is required. This commonly is a television type picture on a CRT, but the faster pattern can be directly printed by a camera on film. Electronic image processing can be incorporated to enhance or enlarge the image or to extract specific information. Electronic pattern recognition or comparison could be employed to automate the accept or reject decision.

ELECTRO-OPTICAL PATTERN RECOGNITION

Perkin-Elmer Corporation has developed an automatic electro-optical pattern recognition system for the Bureau of Engraving and Printing. The developmental model of this equipment is currently being used to inspect sheets of

U.S. currency. Each new bill is compared electronically to a master reference bill whose image is stored in a computer. The images are compared on pixel by pixel basis. Flaw discrimination is accomplished by generating exceedance data for each pixel (the position or negative difference between the features of the examined pixel and those of the stored master pixel). Computer algorithms determine the reject criteria for the note as a whole. The scan head that examines the notes is a charged coupled device (CCD) detector. It has 1024 photosites, with two adjacent sites representing a single pixel. Thus, each pixel is 0.3 mm square. For each pixel a four bit digitized word is generated representative of that 0.3 x 0.3 mm pixel. There are eight scan heads in line allowing simultaneous inspection of eight bills. This facility inspects the front and back of 6000 sheets of bills, 32 to a sheet, in one hour. A significant part of the equipment hardware and software is involved in transporting, aligning, registering, flipping, sorting, and stacking the sheets of bills. Such a device could be adapted to the examination of magnified images of integrated circuit chips and making a pixel by pixel comparison with a perfect master image.

Evaluation of Internal Visual Inspection

The internal visual inspection of integrated circuits is a very involved procedure. As integrated circuits continue (as they will) to become smaller and more complex, the probability of a defect being detected by a visual inspection will decrease. The exception would be gross physical defects which would probably be detected in later screening tests anyway.

The fact that this is a human visual inspection gives rise to further problems. First of all, there is a limit to the speed with which an operator can perform the inspection. Second, in any human inspection a certain number of rejects are going to slip through. This number increases as the inspection rate goes up. Finally, there is the problem of subjectivity in the inspection. What one operator would reject, another might pass. Thus, the speed and effectiveness of the inspection is degraded by the fact that it is performed by humans, and this degradation can be expected to become more pronounced as the complexity of the integrated circuit increases.

Availability of Automated Inspection Systems

None of the IC manufacturers contacted by Columbia Research currently have available an automated system to perform the pre-cap visual inspection. Few of the instrument manufacturers are even working on it. The primary reason given for this is that the inspection itself is so complex. Three manufacturers (KLA, Hitachi, and Contrex) attempting to automate the inspection process were discussed in the section entitled Automated Inspection Systems. Detailed information is not available at this point because the systems are still in the development stage, and much of the information is proprietary. Thus, a best buy prediction, even among these systems, cannot be made at this time. Also, there may still be other systems under development that have not come to the attention of Columbia in the course of the survey.

Further Studies Required

It is recommended that the following actions be taken to resolve questions unanswered by the present survey and to provide important additional information required by ARRADCOM to make an informed technical decision as to the feasibility and cost effectiveness of automating the pre-cap visual inspection of integrated circuits:

(1) Evaluation of the necessity and effectiveness of the pre-cap visual inspection should be undertaken. As part of this evalaution, the IC manufacturers should be tasked to tag the chips failing the visual inspection and then allow them to continue through the screening process to see if they are detected in subsequent tests.

(2) To obtain the detailed information on cost and predicted availability required to make a best buy determination regarding an automated test system, a Request for Proposal should be issued for the establishment of such a system.

(3) To verify the superiority of the automated system over human visual inspection, a test program should be established in cooperation with the IC vendors in which a large sample of chips is inspected sequentially by both systems. A statistical analysis should be performed on the resulting data to compare the relative screening effectiveness of the automated and human systems.

(4) The progress of private industry (KLA Instrument Corporation and Contrex, Inc.) engaged in the research and development stages of this technology should be monitored. If techniques become available, a future MTT project to adapt them to specific components of interest to the Army should be pursued.

M1 Abrams Tank NDT Program

Efficient and Sophisticated Inspection

By
Don Pope
Project Engineer
U. S. Army Tank-Automotive Command

The overall objective of a recent Mantech program for the Army Tank—Automotive Research and Development Command was to formulate and implement a nondestructive program that would establish effective inspection procedures for the verification and acceptance of M1 tank hardware. To accomplish this objective, the contractor-chrysler Defense, Inc.—conducted fifteen specific tasks.

Ultrasonics Manual Developed

Chrysler has developed an efficient and sophisticated NDT inspection system for the M1 tank program—for castings, forgings, and armor welds, they established inspection methods and operating procedures for ultrasonics, radiography, liquid penetrant, magnetic particle, and eddy current for use directly on-line. Chrysler developed a nuclei of highly trained and efficient NDT engineers and technicians who, with their combined effort, will continually update and improve the quality of NDT inspection methods.

However, the most significant benefit derived from the program was the development of an ultrasonic inspection procedures and standards manual for armor welds. Application of ultrasonics as a weld inspection method will reduce inspection costs to about one third of those required for radiography.

Fifteen Tasks Conducted

Fifteen separate but interrelated tasks conducted to complete this program included:

- Review M1 quality control requirements
- Continuously survey state of the art
- Select appropriate NDT methods and define application techniques.
- Identify and procure inspection equipment.
- Establish standard inspection procedures for all selected methods.
- Prepare initial ultrasonic weld inspection procedures.
- Establish parameters for personnel qualification.
- Conduct an in-house training and certification proprogram for production inspection personnel.

NOTE: This manufacturing technology project that was conducted by Chrysler Defense, Inc. was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The TACOM Point of Contact for more information is Don Pope, (313) 574-8328.

- Verify NDT inspection methods on qualification hardware.

- Document test methods and prepare position charts for radiographic and ultrasonic inspection.

- Evaluate and establish an automatic ultrasonic inspection system for armor assemblies.

- Establish sampling plan inspection rates for M1 hull and turret structures.

- Implement NDT inspection procedures for use in production.

- Verify inspection procedures on preproduction and initial production structures.

- Prepare a manual on ultrasonic inspection procedures and standards for armor welds.

Four NDT Methods Suitable

About 1,000 manufacturing process drawings, machine drawings, and quality assurance requirements (QAR) representing major critical components of the tank were reviewed for (1) selection of NDT methods and (2) determiniation of percent and frequency of inspection. Chrysler determined that 107 components were suited to four NDT inspection methods: ultrasonics, liquid penetrant, magnetic particle, and radiography. Also, about 700 NDT technical reports, papers, and publications were reviewed which consisted of the following NDT methods: ultrasonics, radiography, magnetic particle, liquid penetrant, eddy current, and acoustic emission. In addition, contractor personnel attended conferences, seminars, and equipment demonstrations concerning various NDT methods and application techniques.

Selecting Methods and Their Application

Selection of the majority of NDT methods and definition of their applications was accomplished simultaneously with review of the M1 quality control requirements. Automation feasibility studies for all NDT methods were conducted at various stages of production.

Radiography techniques involved use of 2-MEV linear accelerator X-ray unit for hull and turret weldments and suspect castings that are thicker than 2 inches. A 300-KV portable X-ray unit is used for hull and turret weldments and suspect castings that are up to 2 inches thick. Further, 420-KV X-ray unit is used for welder qualification plates, ballistic H plates, and small castings that are 3 inches or less in thickness. After a thorough review of the automated systems available for radiography, it was decided that none of the systems would be economically feasible or practical.

Liquid penetrants are used to inspect completed hull and turret weldments, suspect castings, forgings, and flame-cut edges for surface indications (i.e., cracking, porosity, and plate laminations). Liquid penetrant proved ineefective on areas where the temperature exceeds 150 F. Automation of liquid penetrant inspection is impractical for the M1 tank program.

Magnetic particle inspection is used on rework areas of the hull and turret weldments and casting and forging repairs where interpass temperatures of 150 F or greater have to be maintained until rework or repair is completed. The limited use of magnetic particle inspection in production does not necessitate the use of an automated system.

Through experimentation, it was determined that the **eddy current method** was too time consuming and uneconomical to be used as a production inspection method on hull and turret weldments. It is being used for alloy sorting, case hardness depth checks, and plating thickness measurements. Because the use of eddy currents is limited to special types of inspections, automation is unnecessary.

At this time, **ultrasonics** is being used to locate flaws found by X-ray of hull and turrent weldments for ease of rework. It also is being used on armor assemblies; however, the material and the inspection procedures are excluded from this report. Various automated ultrasonic inspection systems were studied to determine adaptability to inspect welds on the M1 tank. However, because of the numerous and varied weld joint configurations, it was decided that automation would be impractical and uneconomical.

Operating Procedures Established

Twenty three standard operating procedures in the form of quality control instructions were established for all selected NDT methods. The instructions are in the contractor's format and include both general and specific directions based on MIL-Q-9858A requirements. The instructions also denote the applicable level of NDT personnel certification requirements. Listed below, they were used to implement and control the NDT program and will be updated as the need arises.

- NDT Methods and Their Applications

- Ultrasonic Inspection of Partial and Full Penetration Welds

- Ultrasonic Inspection of Armor Assemblies (Manual Method)

- Ultrasonic Inspection of Armor Plate
- Ultrasonic Inspection of Forgings
- Ultrasonic Calibration (Angle Beam Transducers)
- Ultrasonic Thickness Measurements
- Ultrasonic Inspection of Steel and Armor Castings
- Radiographic Location of Flaws
- Magnetic Particle Inspection (General)
- Magnetic Particle Inspection (Torsion Bars)
- Liquid Penetrant Inspection
- Visual Inspection of Welds
- Eddy Current Inspection (General)
- Eddy Current Inspection (Plating Thickness)
- Eddy Current Sorting of Ferrous Metals
- Eddy Current Inspection (Case Hardness Depth)
- Eddy Current Inspection (Material Hardness)
- Radiation Safety Requirements for Industrial X-ray Equipment
- Ultrasonic Calibration (Horizontal and Vertical Linearity)
- Personnel Qualification and Certification
- Welder Certification

Ultrasonic Weld Inspection Procedures and Standards

The scope of work to prepare initial ultrasonic weld inspection procedures and standards comprised five parts:

(1) Review existing ultrasonic inspection procedures for full penetration welds to assist in establishing procedures for the M1 tank, which consists primarily of partial penetration welds.

(2) Establish ultrasonic inspection scan procedures for hull and turret weldments.

(3) Establish standard procedures for ultrasonic instrument calibration and documentation of inspection results.

(4) Verify ultrasonic scan procedures through radiographic correlations.

(5) Establish ultrasonic accept/reject criteria.

To establish a base for writing preliminary ultrasonic scanning procedures on welds, Chrysler reviewed specifications available from the American Society of Testing Materials, American Society of Materials Engineering, American Welding Society, and the U.S. Navy. With the help of such review, they wrote procedures that will ensure the integrity of weld joints consistent with M1 production goals. The procedures were based on developed NDT requirements, state of the art methods, and experimentation.

Ultrasonic inspection results were correlated with radiography to verify the type and severity level for determining quality levels for acceptance standards. Figure 1 shows a weld cross section and a portion of a radiograph of that weld. The actual full size radiograph shows a continuous discontinuity in the outer weld nugget in the root area.

Ultrasonic examination placed the disconinuity along the indicated weld to parent metal interface. The cathode ray tube (CRT) presentation depicted in Figure 1 shows a relatively clean spike with an amplitude of approximately 35 percent.

Personnel Training and Certification

The scope of work for training and certification of personnel comprised six parts:

(1) Prepare quality control instructions (QCI) covering training and personnel certification requirements necessary to perform the NDT functions established for the M1 tank production program.

(2) Establish training course outlines for each NDT method.

(3) Procure training material for all NDT methods to be used.

(4) Conduct Levels I and II in-house training for all methods.

(5) Provide on-the-job training experience for all methods and levels as required.

(6) Prepare and conduct certification examinations for all methods and levels.

A procedure for personnel training and certification was written. Included in it are the training outlines for all NDT methods being used in production. Also, training

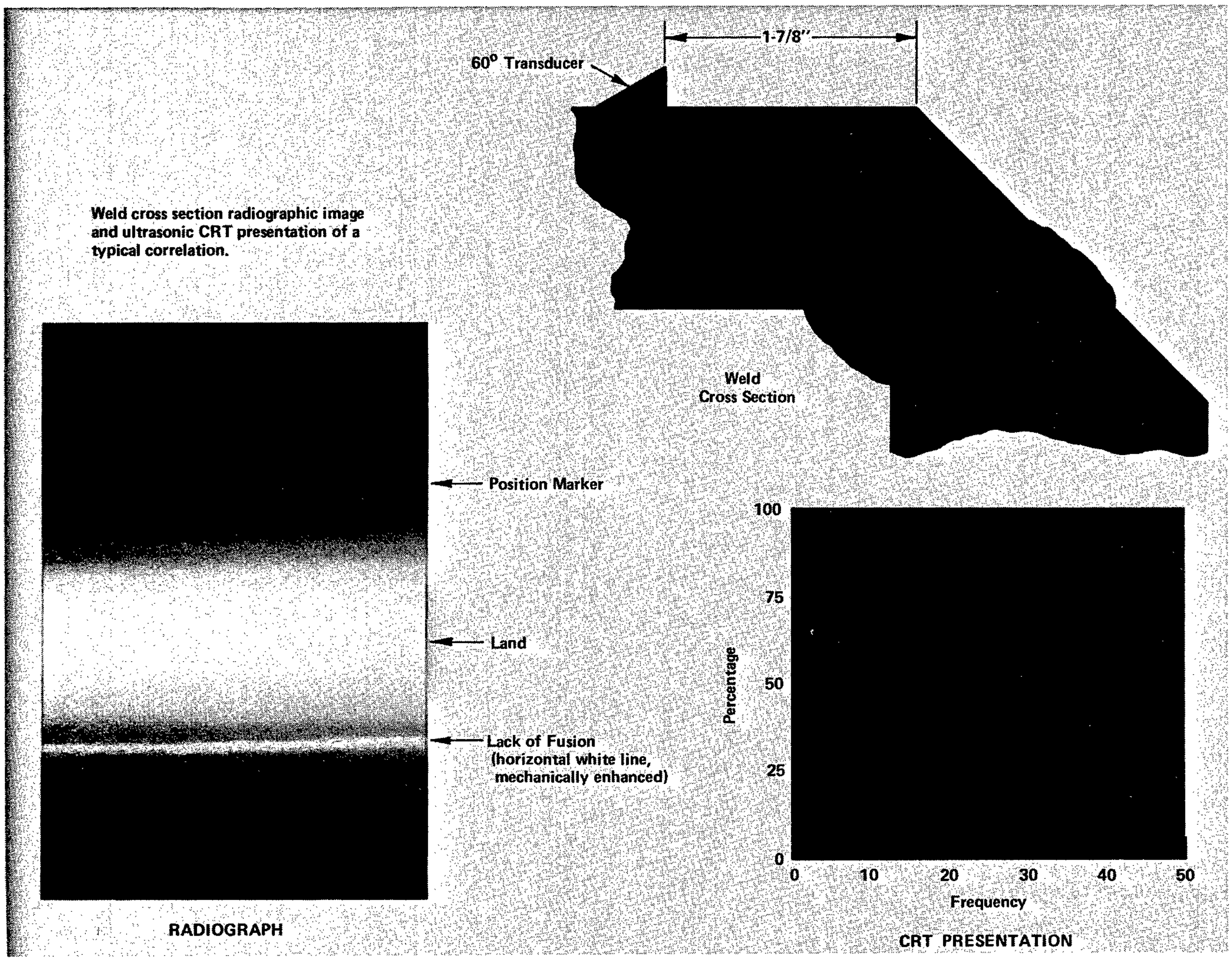


Figure 1

films and instruction manuals were procured for Levels I and II in-house training for each NDT method. Contractor personnel were trained at vendors' schools such as Krautkramer-Branson, Magnaflux, DuPont, and Automation Industries. These personnel then conducted in-house and on-the-job training courses for other personnel.

Ultrasonic Weld Inspection Manual Prepared

The purpose of this work was to compile data from associated tasks and to prepare an ultrasonic weld inspection manual which would include the following:

- Basic principles of ultrasonic inspection
- Personnel certification requirements
- Instrument calibration procedures
- Accept/reject criteria
- Standard scan procedures for M1 tank joint configurations
- Limitations of ultrasonic inspection
- Flaw classification using a computer assist system
- Standard procedures for documentation of results.

All the preliminary work for the manual for seven of the eight tasks listed above has been completed. Work on the eighth task, flaw classification, continues.

Fabrication of YAG Laser Rods

8-Fold Production Rate Increase

By
Jeff Paul
Project Engineer
U. S. Army Electronics Research and Development Command

A manufacturing technology project completed by Litton Industries for the U.S. Army Electronics Research and Development Command has successfully developed efficient new fabrication methods for meeting the Army's laser production needs.

The Nd:YAG (neodymium doped yttrium aluminum garnet) solid state crystal laser is the most widely used and studied device for present and future military applications. Since its discovery, Nd:YAG has proved to be a nearly ideal laser material, so increased rod requirements are a certainty for all service branches. However, two persistent production problems have slowed the more extensive use of Nd:YAG in the form of low cost rods. The first of these was (1) the availability of high purity and optically perfect rough boules capable of good yields. In 1970, the U.S. Army addressed itself to this area and a successful program was completed. The second problem involved (2) the fabrication of laser rods using techniques of batch processing in place of unit operations.

Demand High, Production Low

During the period 1970-1975, Nd:YAG laser devices experienced a period of advanced engineering development. At this stage the normal rod usage attained a maximum of 1-5 rods/month. Laboratory procedures for fabrication were developed and all operations were done by hand on each rod. At the present time, the Army laser programs include items such as the AN-VVG-1 laser prorange finder, the GLLD locator designator, laser tank range finders, and the AN/GVS-5 hand held range finder. Similar programs and expanded plans are forecast for the Navy and Air Force. Thus, the production requirements of Nd:YAG are rapidly increasing and are already in excess of 500 rods per month. It therefore has become imperative to develop procedures for laser rod fabrication which accomplish increased production yields per man-hour. This program was conducted by the Airtron Division for the Solid State and Injection Laser Team of the Night Vision and Electro-Optics Laboratory, Fort Belvoir, Virginia.

NOTE: This manufacturing technology project that was conducted by Litton Industries was funded by the U.S. Army Electronics Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ERADCOM Point of Contact for more information is Jeff Paul, (703) 664-4766.

It relied on the fact that high quality material is available and also that the preliminary machining operations necessary to produce rough rods of material are basically available as are the techniques required for the coating and testing of the finished rods. Therefore, this program was directed at developing techniques for the batch grinding and polishing of rough rods to produce finished laser rods.

AN/GUS-5 Chosen

The laser rod configuration chosen for the development of batch grinding and polishing techniques is that of the component used in the AN/GVS-5 hand held laser range finder. This system represents the first system to go into volume production and is thus appropriate for the development of manufacturing techniques. The rod itself is smaller in length and diameter than rods used in the majority of military systems. Other specifications, however, are typical.

The input material to the program was single crystal neodymium doped yttrium aluminum garnet (YAG). From the single crystal boule, areas are selected which are of high optical quality. These areas are then used to core drill rough rods, which subsequently are centerless ground and sized in preparation for the final polishing operation.

The laser rod to be produced was a 4.27 mil diameter by 43 mil long rod. The outside diameter was to be of rough ground finish. Starting with rods of material having rough ground end faces, finished laser rods having a latness within 0.2 wavelength of sodium light and a surface finish better than 20-5 per MIL-13830 were to be produced. The end faces were to be parallel to within 20 sec arc and perpendicular to the rod axis within 5 min of arc.

Fixture Design

At the start of this program the majority of the fixturing in application in laser rod fabrication (Figure 1) was designed to hold a single rod during the grinding and polishing operations. The laser rod to be polished is held at the center of the fixture surrounded by polishing feet.

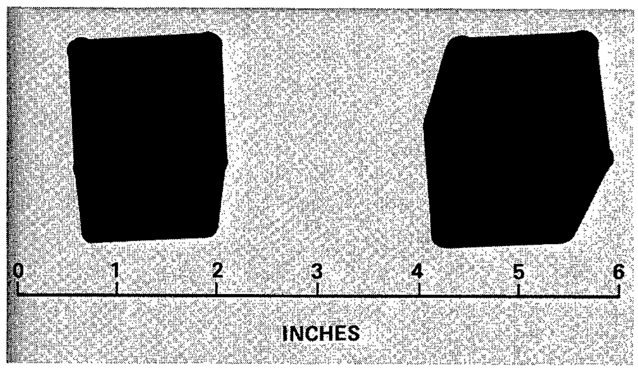


Figure 1

When one end of the rod is polished the rod is dismounted, turned and remounted. The second end is then ground and polished. This process yielded one rod per 5 man-hours.

Experiments previously performed on batch fabrication indicated the yields that could be expected from a fixture designed to hold twelve rods. Data showed that under laboratory conditions and for the rod sizes attempted yields of 65-85 percent could be achieved when the critical parameters were considered.

Three basic requirements existed for the design of an appropriate fixture for batch grinding and polishing:

- The fixture must hold a sufficient number of rods such that when yield characteristics are considered the design goal of the program will be achieved.
- The design must be such that rod specifications are met with a reasonable yield.
- The size and design of the fixture must provide for the fact that the grinding and polishing would be performed by hand.

For the fixture to perform well in a manufacturing process, all of the above criteria would have to be met.

The number of rods held by the fixture was derived from the yield data generated in earlier experiments. The design goal of the program was to achieve a rate of twelve fabricated rods per 8 man-hours.

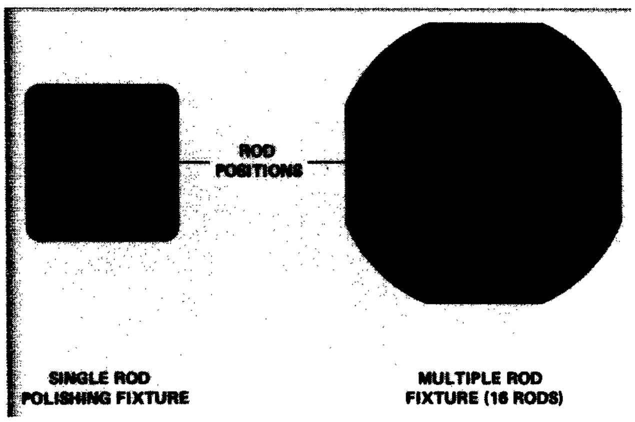


Figure 2

Fixture Design Adopted

The final design adopted for the fixture (Figure 2) is a block 3 inches in diameter and 1-9/16 inches thick. The block has flats ground on the sides to provide a convenient method of resting the block. It is made of a quality tool steel and has a thickness which will accommodate the 44 mm length rods, leaving both ends exposed.

To provide mounting for the laser rods, holes are bored through the block. There are eight holes located on each of two bolt circles—one 1.562 inch in diameter and the other 1.062 inch in diameter. The hole is 5/16 inch in diameter to accept a standard size bushing. These bushings are pressed into the block at each end and hold the rod (at each end) without constraining the center. This technique eliminates the stressing of the rod in the fixture.

Also, because during the finishing of the laser rod second ends it is possible for the first ends to become contaminated with the polishing grit and subsequently damaged, the finished ends were covered with an aluminum protective cap. This cap is 2.25 inches in diameter and is held in place using a 1/2-20 bolt with an "O" ring seal.

The holes in the block are perpendicular to the face within 0.0003" TIR, or to less than 1 minute. Assuming the smallest rod diameter and the largest bushing inside diameter allowed, the rod and bushing perpendicularity is within 2.5 minutes. Thus, a perpendicularity of less than 3.5 minutes should be maintained for all rods.

Polishing feet or dummies are located on each end of the block on a 2.625 inch diameter bold circle. Each rod is thus symmetrically surrounded and the surface will work evenly. In addition, the block will be stable.

Manufacturing Rate Exceeded

The design goal of this program was to achieve a laser rod manufacturing rate of 12 rods per 8 man-hours. During the engineering phase of the program the necessary tooling and process were developed to fabricate blocks of sixteen laser rods of the AN/GVS-5 configuration. The results of the program indicate that a rate in excess of fourteen rods per 8 man-hours was achieved, thus exceeding the rate required by the program and saving about $30 per rod ($180,000/year at current needs).

No major difficulties were encountered in achieving the desired rate at the rod specification required. A minor difficulty was encountered originally in controlling changes in parallelism between mounted and dismounted rods. This was overcome by exercising more care in mounting.

Rate variations between blocks were significant (3 to 13 hours per block). These variations were found to be independent of the operator and were minimized during the later stages of the program when more experience with the process was gained.

The program was successful in achieving a dramatic reduction in the number of man-hours required to fabricate a finished laser rod. The process has been applied to the AN/GVS-5 hand held laser rangefinder. As part of this program, a process demonstration also was held.

More Automation Coming

The process developed was successful for 4.27 mm by 43 mm laser rods. In future work, the results of this effort should be extended to other sized laser rods. In addition, this work was directed at a parallelism tolerance of 20 sec of arc. For many applications a tolerance of 10 secons is required. At the latter tolerance, a significantly reduced yield is obtained. Efforts at improving the yield at this specification should be made.

This process relies heavily on the operator to control parameters. If even higher process rates are required, it will be necessary to develop processes where this reliance on the operator is reduced.

Commercial Welding Techniques Used

Joining Dissimilar Metals

By
Buck Schevo
Project Engineer
U. S. Army Tank-Automotive Command

Reduction in weight and improvement of performance are matters of significance in the design and manufacture of armored military vehicles. These objectives must be reached without materially sacrificing ballistic protection. Manufacturing methods to produce more efficient designs must be economically feasible, but also should rely on tools, materials, and skills readily available in the supplier community. Further, these methods must have proven service reliability.

Therefore, a test program was initiated by the U.S. Army Tank-Automotive Command to evaluate the use of roll bonded and explosive bonded bimetal transition materials in joining steel and aluminum armor for military vehicles. The goal was to verify that commercially available steel/aluminum transition strips can be used successfully with production welding techniques to fabricate vehicles. Ballistic tests were performed to determine the integrity of butt and corner joints obtained on samples of one inch steel and aluminum armor plate.

Successful application of this technology to armor in production would make it possible to optimize ballistic protection as well as vehicle weight and performance.

Transition Strips the Key

Replacement of steel armor with aluminum in certain areas, such as floor panels, or the addition of steel armor in aluminum vehicles has been suggested as one way to arrive at optimum weight/protection designs. Aluminum and steel cannot be joined directly, however, by conventional welding techniques. The use of mechanical fasteners not only introduces undesirable stress concentrations, but also limits design flexibility and provides the opportunity for secondary missiles in combat service.

For a number of years, transition strips fabricated by explosion bonding or roll bonding of dissimilar metals—which cannot be joined by conventional welding—have been available to industry. These materials have been in use for several years for welding applications in electrical and fabrication industries, including the joining of steel and aluminum. They had not, however, been verified for heavy steel and aluminum armor manufacturing applications.

NOTE: This manufacturing technology project that was conducted by the Combat Systems Division was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The TACOM Point of Contact for more information is Buck Schevo, (313) 574-5814.

Roll vs. Explosion Bonding

To verify the welding of steel and aluminum armor and subsequent ballistic testing, samples of commercially available explosion bonded and roll bonded layered aluminum/steel transition strips were selected. The explosion bonded sample was DuPont Spec 604M ("Delta Couple"), 1-3/8" thickness, consisting of 3/4" steel ASTM 516Gr55 and 5/8" aluminum 5086 or 5456 with an 1100 aluminum interlayer. The roll bonded specimen was Kaiser Spec KA-09006A, 7/8" thickness, consisting of 1/2" aluminum 3003 and 3/8" steel 304 stainless with an 1100 aluminum interlayer. No Federal specifications for either of these transition materials exist at this time.

Butt and Corner Joints Selected

Butt and 90 degree corner joints were chosen for tests to simulate potential design requirements. One inch rolled steel armor MIL-A-12560 and one inch aluminum MIL-A-46027 in the form of flat plates nominally 18" x 36" were joined using the joint geometry indicated in Figure 1. These configurations were selected on the basis of recommendations from suppliers of the transition strips.

Welding techniques were critical, since overheating of the transition material would degrade the bimetal interface. DuPont in the guidelines furnished with its material specified that the interface temperature remain below 600 F to prevent the formation of brittle intermetallic compounds. Kaiser Aluminum specified a maximum interface temperature of 800 F. Interface temperatures were minimized by providing the maximum practical heat sink and by reducing the heat input to the weld.

Width of the transition strips was chosen to be 4", or four times the plate thickness, to allow for heat distribution and compensate for possible small bonding defects. Such a guideline on width also permitted fillet welding which reduced the possibility of penetration and consequent destruction of the steel/aluminum interface.

Aluminum Side Welded First

The aluminum side of the joint always was welded first to provide a larger heat sink while welding the steel side; no weld preheat was provided. In all cases, stringer beads were used to maintain low interface temperature. Interpass temperatures were measured using surface pyrometers and were not allowed to exceed 600 F for any specimen at the steel/aluminum interface.

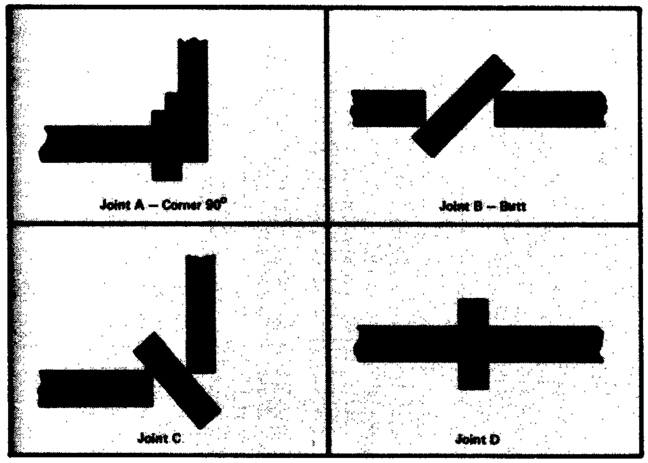


Figure 1

Edge preparation for all specimens consisted of 90 degree square cuts; when required, they were machined. Steel armor was flame cut to size. Both corner and butt joints were tilted after setup to allow flat horizontal welding. On Type "A" specimens, steel was machined off the transition strips approximately 1/2 inch from the aluminum fillet weld to protect the interface (Figure 2).

Welding was accomplished using a gas metal arc, semi-automatic technique, with a 500 Ampere dc rectifier. Shielding gas for aluminum was 100 percent argon at 40 cFH, and for steel it was 97 percent argon with 3 percent oxygen at 50 cFH. Welding electrodes were 1/16 inch diameter aluminum Type 5356 MIL-E-16053 and steel Type B88 MIL-E-19822. In all cases, beads were laid alternately on both sides of the armor plate to minimize residual stress and interface temperature.

Figure 2

Overall, twenty-four specimens were fabricated, which represented eight different combinations of joint geometry and transition materials (Table 1). When radiographic examination was performed on the first ten weldments, it was found that steel welds frequently exhibited linear porosity, while aluminum welds showed scattered porosity. In two cases, steel fillet welds exhibited cracks in corner joints. In general, however, specimens examined were radiographically acceptable and further radiographic tests were excluded.

Impact Velocities Monitored

The twenty-four fabricated specimens described were transported to the U.S. Army Aberdeen Proving Ground for ballistic testing. In each case, the aluminum side of the weldment was impacted first using 75 mm M1002A aluminum plate proofing projectiles from a 75 mm howitzer. The steel side (of the same specimen) was then tested using 57 mm M1001 steel plate proofing projectiles from a 57 mm gun. Striking velocities were measured using Weibel sky screens and circuit break screens. Striking velocity was adjusted after testing the first weldment of each joint type to attain the highest velocity without catastrophic cracking.

Tests were performed at ambient temperature (39 F); no low temperature tests were performed. During firing, specimens were held in a heavy steel frame consisting of two vertical components and a base plate. Impacted surfaces were perpendicular to the line of fire. Corner specimens were impacted on the outside angle.

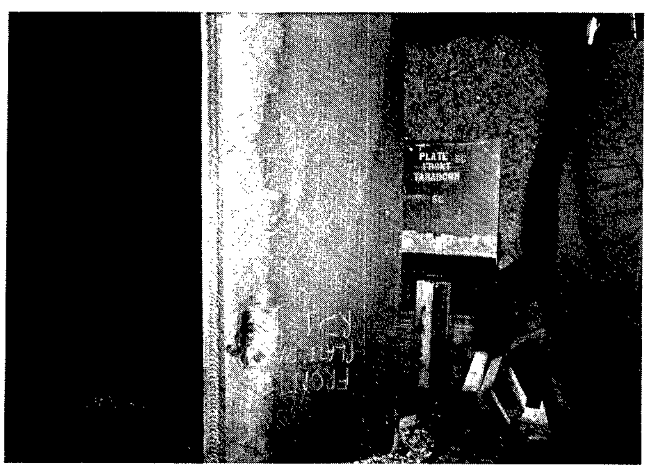


Figure 3

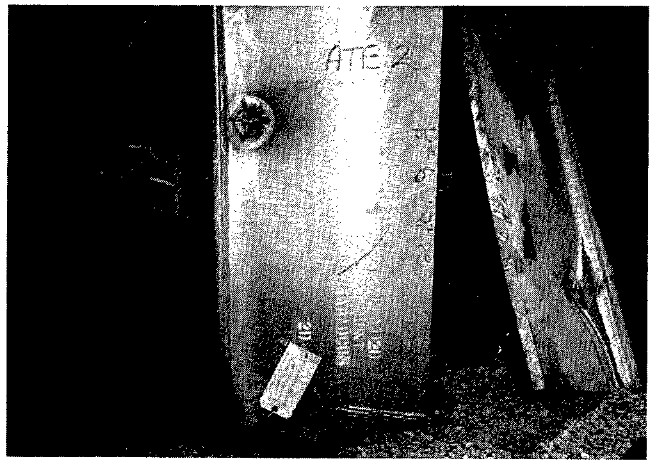


Figure 4

Results Striking

Ballistic tests of the samples demonstrated that the transition strips performed at least as well as the armor plate itself or the welds (see Figures 3 and 4). For example, of 48 impacts there were five transition strip failures out of a total of approximately 80 failures noted. For purposes of this discussion, a failure occurred when a crack was visually detected in the assembly.

Although differences in performance of the joints were small, results on the aluminum side suggested that Design A (Figure 1) withstood ballistic impact better than Design C. In these assemblies, there was less cracking and displacement of components after impact. This effect was due, in most part, to the stiffer mechanical configuration of Joint A which tended to support the aluminum plate at the weld. The greater strength of groove welds in Design C was insufficient to overcome this effect. A similar effect was seen in a comparison of Joints B and D, where Joint B provided greater mechanical rigidity and slightly better performance.

Unlike the specimens tested, plates in actual vehicles probably would be supported on three or four sides by welds. Because of added support of such an arrangement, these welds should perform better than the specimens tested.

Aluminum/Steel A Strong Contender

Designers of armored combat vehicles should consider aluminum/steel structures to meet current requirements of performance, based on the results of these tests.

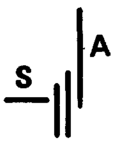
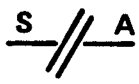
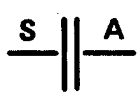
Spec. No.	Joint Type	Transition Material	Aluminum			Steel		
			Passes	Volts	Amps	Passes	Volts	Amps
1A		Roll Bonded	8	28	230	6	28	300
2A		Roll Bonded	8	28	230	5	25	250
3A		Roll Bonded	9	29	240	5	26	290
4A		Explosion Bonded	9	28	260	6	26	285
5A		Explosion Bonded	9	28	260	6	26	285
6A		Explosion Bonded	6	26	250	8	27	285
1B		Roll Bonded	10	25	280	10	25	270
2B		Roll Bonded	8	25	280	12	27	270
3B		Roll Bonded	10	25	260	16	25	260
4B		Explosion Bonded	9	26	280	11	25	260
5B		Explosion Bonded	10	27	270	14	28	280
6B		Explosion Bonded	10	27	270	16	27	290
1C		Roll Bonded	12	27	320	17	24	240
2C		Roll Bonded	12	27	320	17	24	240
3C		Roll Bonded	12	27	320	17	24	240
4C		Explosion Bonded	12	26	310	17	25	310
5C		Explosion Bonded	12	26	310	17	25	310
6C		Explosion Bonded	12	26	310	17	25	310
1D		Roll Bonded	8	27	270	8	26	280
2D		Roll Bonded	8	27	270	8	26	280
3D		Roll Bonded	8	27	270	8	26	280
4D		Explosion Bonded	10	27	270	6	26	280
5D		Explosion Bonded	10	27	270	6	26	280
6D		Explosion Bonded	10	27	270	6	26	280

Table 1

However, design of steel/aluminum armored vehicles should be approached with due attention to joint design and welding procedure, not only to minimize the danger of damage to the transition strip but also to account for thermoelastic effects. Because of the difference in thermal expansion coefficients between steel and aluminum, the in-homogeneous nature of heating during welding, and the rigid nature of thick gage armored structures, conditions exist which could result in high residual stress as well as structural forces. Given the typical service requirement of impact loading, these conditions could contribute to brittle behavior if not carefully controlled. And, because of the interaction between structural rigidity, the state of stress, and low temperature behavior of steel, designs intended for service in cold regions should be subjected to low temperature impact testing.

Proposed designs also should consider the effects of corrosion of dissimilar metals, particularly in applications where vehicles will be subjected to salt or saltwater exposure. Both galvanic corrosion and stress corrosion (of high strength aluminum) should be controlled.

Cleanliness Essential

Projectile Banding Via Inertia Welding

WILLIAM R. SHARPE is a project engineer for the U.S. Army Armament Research and Development Command at Dover, N.J., where he works on metallurgy related projects in the Munitions Systems Division of the Large Caliber Weapon Systems Laboratory. He attended the University of Notre Dame, receiving a B.S. in Physics and an M.S. in Metallurgy. From there he began his government service at Frankford Arsenal, Philadelphia, where he acquired a strong background in the munitions metal parts field. He has been in his present position for 5-1/2 years.

Disbond free welds can be obtained by inertial welding of banding onto 155-mm projectiles if the band seat and rotating band are clean. Disbond free welds also can be achieved when certain lubricants are used. Such were the findings from a recently completed manufacturing technology project sponsored by the U.S. Army Armament Research and Development Command.

Early in 1981, the Chamberlain Manufacturing Corp. undertook a project for the Munitions Systems Division to define the process parameters for inertia welding of rotating bands to the 155-mm M483A1 projectile on the high-capacity inertia welder at the company's New Bedford Division (Figure 1).

To help prevent areas of disbond at the weld interface, program researchers initially studied cleaning and storage procedures to minimize oxidation and impurity levels on the rotating band and projectile band seat prior to welding. Also, while optimum inertia weld parameters were being determined, nondestructive ultrasonic testing of the inertia welds was verified by correlating data from two sources: (1) ultrasonic scanning on the linear transducer array at the Army Materials and Mechanics Research Comman (AMMRC); and (2) ultrasonic scanning on the single transducer scanner at Chamberlain R&D, Waterloo, Iowa. These data were compared to data from destructive shear and bend tests to verify ultrasonic scanning as an accurate and reliable inspection method for inertia welds.

Traditional or Axial Thrust vs. Radial

In traditional inertia welding in which the parts to be welded are brought together by an axial thrust, surface contaminants are driven out of the weld area by the "washing action" of the upset of material at the weld interface. Because of this cleaning action during welding, little needs to be done to prepare the surfaces being welded. On the other hand, in inertia welding of rotating bands to projectiles, the axial thrust of the welder is converted to a radial motion and the nature of the weld, with minimal upset, is such that there is little self-cleaning action. Most of the contaminants on the surfaces being welded are expected to be trapped in the weld. These contaminants can include materials used in machining operations, coatings applied after machining, inert material deposited during storage (dust, oil, film, etc.), or reactants formed during storage (e.g., metal oxides).

NOTE: This manufacturing technology conference that was conducted by Chamberlain Manufacturing Corp. was funded by the U.S. Army Armament Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Bill Sharpe, (201) 724-2522.

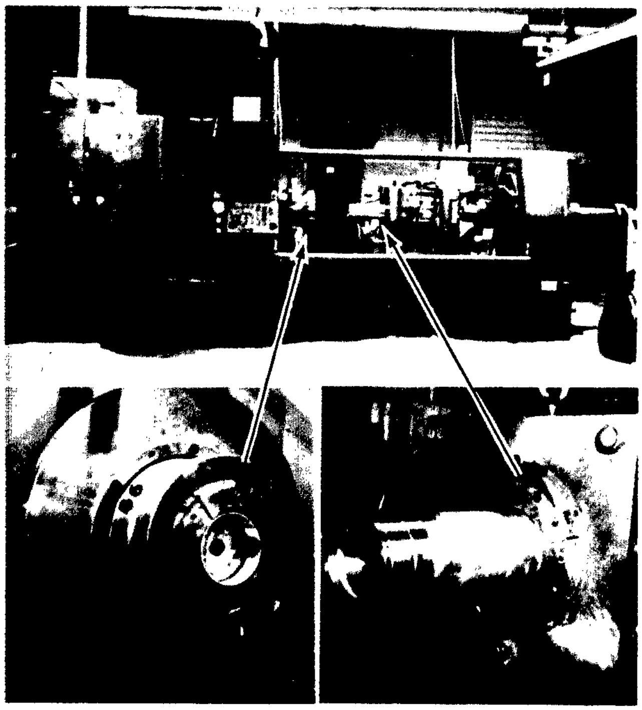


Figure 1

In order to minimize their detrimental effect it was found that either acid etching the bands or machining them without using a lubricant were acceptable band cleaning methods. A detergent wash and hot water rinse, followed by immersion in chemical degreaser, were the accepted steps in cleaning bodies. Various exposure conditions and times were examined; long storage times were found to be deleterious to weld quality. In particular, when acid etching was used on bands, the active surface began to tarnish in 10 to 15 minutes, so it was essential that the welding be done immediately after cleaning. If the band was machined, it could be stored for at least 1 day before welding. Bodies could be stored for longer times (up to 2 months) after machining, but they had to be stored in a sufficiently dry environment so that rusting did not occur (see Table 1).

Inspection—An Essential Factor

A rapid and reliable method for inspecting inertia welded rotating bands was necessary to make inertia welding a viable production process. Inspection by ultrasonic scanning had been used in earlier contract work and was the primary inspection method used in work associated with this contract. In addition, a number of auxiliary destructive tests were performed on sections of welded bands in an attempt to verify ultrasonic scan information and to better understand the welding process.

Nondestructive ultrasonic testing of inertia welds was verified by correlating data from ultrasonic scans on the linear transducer array at AMMRC and the single transducer scanner at Chamberlain. Comparing these data with data from destructive shear and bend tests showed that, indeed, ultrasonic scanning is an accurate and reliable inspection method for inertia welds, with welding done before heat treatment and scanning after.

Heat Treatment/Weld—In What Order?

When inertia welded rotating bands are to be used on projectiles requiring heat treatment, the heat treatment could be performed either before or after band welding. In either case, the inertia welding would heat a shallow region of the band seat above the critical temperature for the steel. The adjacent ambient temperature steel will extract the heat rapidly enough to give an effective quench and to convert the heated material to brittle martensite (Figure 2).

If bands are welded before heat treatment, the martensite layer is, of course, erased during heat treatment. If bands are welded after the projectile bodies have been heat treated, the resulting martensite layer could possibly be left as is, or it could be tempered by heating the steel to the temperature that had been used in tempering the projectile during heat treatment. Inertial welding of bands prior to projectile heat treatment follows the current practice used for projectiles having overlay welded bands.

In work preliminary to making this determination, sixty-one M483A1 projectiles had rotating bands applied

Weld Number	% Bonded Area	Average	Band Preparation and Cleaning[1]
1.1.A	93 35	94 27	Machine dry Acetone wipe[2]
1.1.B	95 18		
1.2.A	92 24	91 46	Machine dry Acid etch[3] Acetone wipe[2]
1.2.B	90 67		
1.3.A	92 17	93 99	Machine with lube[4] Acetone wipe[2]
1.3.B	95 80		
1.4.A	88 45	88 16	Machine with lube[4] Acid etch[3] Acetone wipe[2]
1.4.B	89 87		

[1]All bands stored in polyethylene bags after washing Removed shortly before welding

[2]Band wiped with reagent grade acetone (using clean cheesecloth) immediately before welding

[3]Acid solution: 40% HNO_3 (reagent grade), 60% H_2O (deionized)

[4]Johnson's J-Wax used as lubricant

Table 1

by inertia welding and were heat treated using a relatively fast oil quench. Ultrasonic scanning was performed both before and after heat treatment. This indicated that projectiles with poorly bonded rotating bands show a greater degree of disbond after heat treatment; projectiles with well bonded bands are not adversely affected by heat treatment. One hypothesis to account for this is that intimate contact between the steel and copper band would indicate a good bond before heat treatment, with the expansions and contractions of heat treatment revealing the true nature of the weld. However, experimental work performed at AMMRC and at Chamberlain could not adequately demonstrate this effect. Since this could not be resolved, the current practice of welding before heat treatment was continued, with scanning done afterwards.

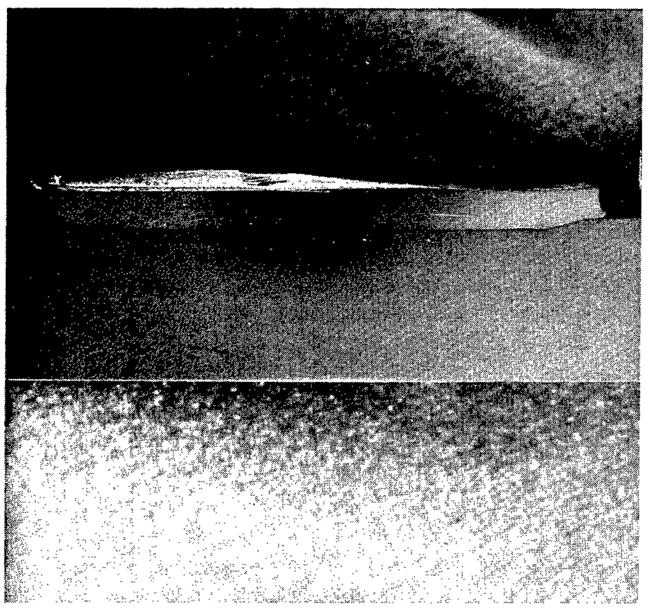


Figure 2

Martensite Layer Formed

An intensive metallurgical examination of the rotating band-projectile body interface was conducted by analyzing microstructure, microhardness, and electron microprobe data: These data show that the heat generated by inertia welding forms a martensite layer under the band-band seat interface and recrystallizes the band material. Analysis shows that the body martensite layer can be as deep as 0.024 inch into the steel. The band recrystallized layer varied up to 0.050 inch in thickness.

Variation of Band and Band Seat Geometry

In work performed under a prior ARRADCOM contract with a marginally acceptable welder (capacity wise) Chamberlain R&D consistently achieved high quality inertia welding of rotating bands to M483A1 projectiles. However, in work performed during this contract with a new, higher capacity welder it was more difficult to obtain consistently good welding along the forward edge of the rotating band. The geometry of the rotating collet that held the rotating band on the marginally acceptable welder was such that when the collet pads were opened to accept the band prior to welding, the pads were not parallel (in the axial direction) to the axis of the projectile body. The collet pad diameter was less at the aft end of the rotating band than at the forward end. As the collet pads closed during the welding operation, the angle between the pads and the projectile axis decreased, and at some specific value of the collet diameter the pads and projectile axis were parallel. On this equipment it was theorized that if the weld was made at the diameter where parallelism occurred, the pressure from forward to aft on the rotating band should be uniform and a good weld should be observed (see Figure 3). If not, there would be some degree of disbond.

On the higher capacity inertia welder used for this effort, the above theory was applied and the collet design was such that the pads were always parallel (see Figure 4). However, as stated, there was a problem with welds on the forward end. An attempt was made to vary geometry to bias pressure toward the forward end in welding. Results were inconclusive and band seat contour was left as in normal production for further efforts.

Lubricants Don't Affect Weld Strength

Inertia welding of rotating bands using various lubricants and coatings on the band blank was studied to determine the effects on tooling and weld quality. In the limited testing performed, certain lubricants extended machine deceleration time, reduced the tooling load (hypothetically extending tooling life), and did not adversely affect weld strength. However, since testing was minimal and results were comparable to previous tests without lubricant, further parameter refinement was done dry.

Process Refinement

In inertia welding, one part is held stationary and the other with a predetermined mass is rotated to a predetermined set RPM. When that RPM is reached, the rotating part becomes free wheeling and the stationary part is thrust into it with a predetermined force. Then the energy associated with the rotating part is converted into frictional heat between the parts to be mated. Just before rotation stops, the two parts bond and the remaining energy hot works the metal interface. Thus, the three parameters associated with inertia welding area: (1) the

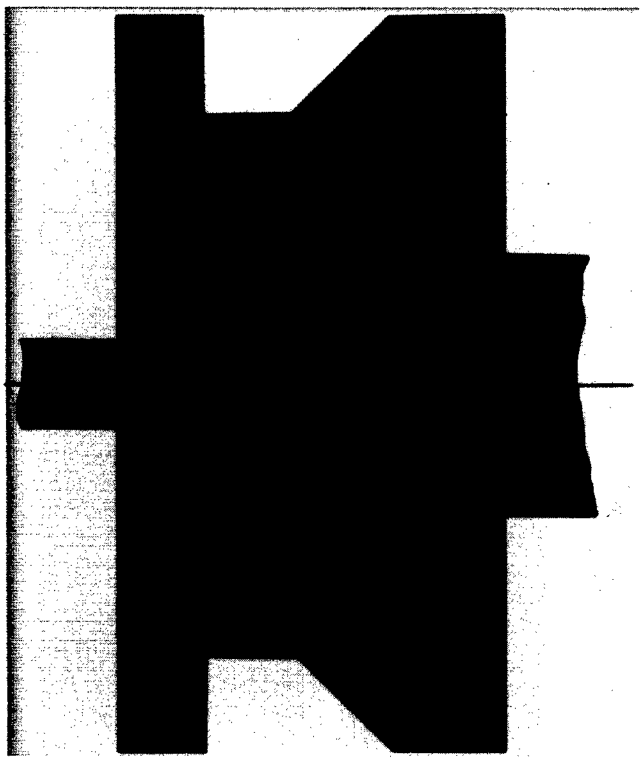


Figure 3

mass associated with the rotating part, (2) the final RPM of that part, and (3) the thrust of the stationary part.

In the case of this application, the stationary part was the projectile body and the rotating one was the band blank. Process refinement efforts involved the varying of all three of the above parameters in order to define the optimum set of parameters to produce a consistent quality weld. Unfortunately, while feasibility was firmly established, inexplicable inconsistencies from weld to weld and machine tooling problems make further study into radial inertial welding necessary.

Test Firings

When a preliminary set of parameters had been determined and the above testing had been completed, twenty abrasion cleaned and heat treated M483A1 projectiles with inertia welded rotating bands were fired in a series of acceptance tests in an attempt to correlate ultrasonics with actual performance and set standards for further work. These projectiles represented a wide range of weld quality. Disbond was much more severe at the leading and trailing edges than at the center of the band. Results indicated that in some areas where the ultrasonic scan indicated disbond at the edge of the rotating band, there was a loss of band material. This loss is believed to be due in some cases to firing and in others to impact. Correlation with ultrasonics was established to a degree, but a larger sample would be required to set ultrasonic standards.

Economic Analysis Needed

Although a great deal of information was gleaned from this work, weld inconsistency remains as a problem to be eliminated, and some secondary questions are left to be answered. For example, an in-depth analysis of available data would be needed to determine whether a positive correlation exists between inertia welding machine parameters and weld quality. If a positive correlation between machine parameters and weld quality was found, then a minicomputer system should be installed on the inertia welder to monitor and display those parameters. This would give the inertia welding machine operator a visual display depicting weld quality.

Additional inertia weld testing also would be needed to determine whether using the proper lubricant materials will provide extended tooling life and more consistent weld quality during production operations. And, finally, an economic analysis should be conducted of the inertia welding process. This analysis should consider all the necessary process/procedures in the inertia welding of a rotating band to determine the cost effectiveness of using the inertia welding process for banding projectiles.

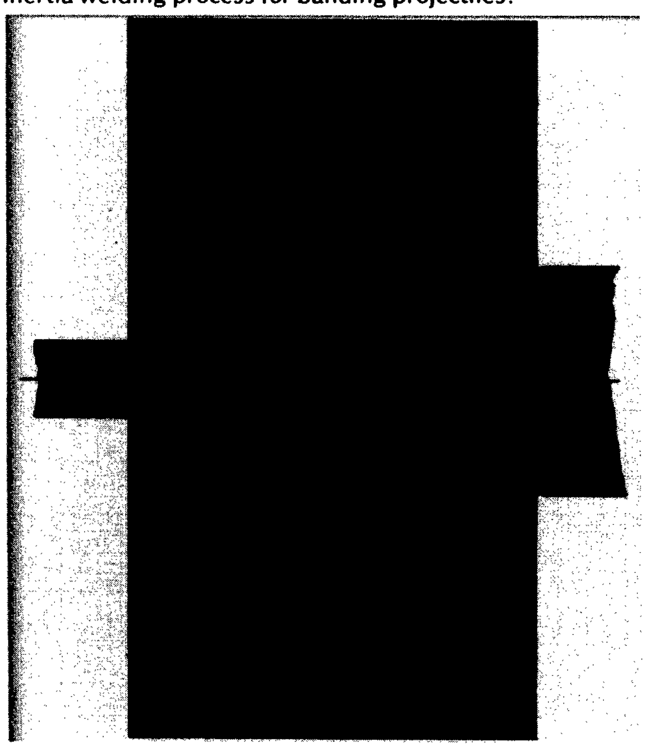


Figure 4

Peering Into the Future

Lightweight Armored Vehicle Vision Blocks

C. DOUGLAS HOUSTON, Jr. is a project engineer with the U.S. Army Tank-Automotive Command, and has been associated with work in vision devices since 1961. He holds a BS in Electrical Engineering from Michigan Technological University. He was also associated with Crysler Corporation on early projects in guided missiles.

A remarkable potential now is available to the U.S. Army Tank-Automotive Command for new transparent viewing systems that offer a level of protection that was considered impossible only three years ago. Where light weight and a high level of protection previously were tradeoffs, now they are welcome companions in the Army's new vision block technology. The new ultimate transparent armor is made up of an outside layer of extremely hard aluminum oxide plate backed by plies of a new high hardness glass and lined by a layer of tough new polycarbonate plastic to act as a spall guard. The new vision blocks are only part of the results from a project sponsored by the U.S. Army Materials and Mechanics Research Center for the Tank-Automotive Command.

Work recently completed by Goodyear Aerospace for the Army Materials and Mechanics Research Center has resulted in this improved capability, and when these vision blocks are incorporated in lightweight armored vehicles, they should increase the operational and survivability aspects of their operation.

The Need for Improved Visibility

Good visibility is of paramount importance to the operational and survivability aspects of armored vehicle performance. Unfortunately, vision blocks currently in use having even modest resistance to armor piercing kinetic energy projectiles have very marginal visibility characteristics. The principal problem is one of low luminous transmittance through the appreciable thickness of laminated soda-lime glass. The problem is increased by poor lighting such as can be experienced with overcast sky or near dusk conditions. The advent of high performance, lightweight armored vehicles such as the XM-2 Infantry Fighting Vehicle, XM-3 Calvalry Fighting Vehicle, Commando Scout Vehicle, Commando V-150 Armored Vehicle, and the MPG-NT Mobile Protective Gun Combat Vehicle has compounded the visibility handicap. Such vehicles, by the very nature of their increased road speed and advanced reconnaissance and fighting mission requirements, make greater demands on operating personnel vision.

During the last several years, great strides have been made in advancing the state of the art in the transparent armor field. The glass/plastic transparent armor concept has resulted in significantly reduced armor weights, improved optical quality, and elimination of backside spalling characteristics. The incorporation of specialty

NOTE: This manufacturing technology project that was conducted by Goodyear Aerospace thru the U.S. Army Materials and Mechanics Research Center was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The TACOM Point of Contact for more information is C. Douglas Houston, (313) 574-6478.

glass also offers the possibility of achieving much higher luminous transmittance and a "water-white" appearance. New and extremly hard materials such as transparent ceramic (aluminum oxide) are now available for use in transparent armor composites. The transparent ceramic material also has high luminous transmittance and "water-white" characteristics. The material components and technology therefore exist which offer a high confidence level of success in achieving significant improvements.

The transparent armor program at the U.S. Army Materials and Mechanics Research Center funded the development of a new high hardness glass by PPG Industries. The performance of this material is such that when used in a vision block, equal protection from impact is provided with far less glass. The resulting thinner block enables a reduction in the surrounding armor "pocket" depth and a weight savings.

Further developments contributed to yet another plateau of vision block technology. These are the tough polycarbonate plastics and the cast interlayer adhesives that bond them to glass and other plastics. These cast interlayers replace polyvinyl butyral interlayers in some instances.

An important new material in transparent armors is single crystal aluminum oxide. This is a product of synthetic crystal technology, which permits a clear, cylindrical aluminum oxide crystal to be produced up to 12 inches in diameter. From this, plates may be cut and polished to a transparent plate, like plate glass, but many times harder.

Applying this aluminum plate as the outboard face of the composite transparency as described above, we have a high ballistic transparency of greatly reduced thickness and, of course, weight. This project of applying a new material to known materials has provided significantly lighter but ballistically superior vision blocks for armored vehicles.

Objective: Maximize Visibility

The program was divided into two phases, and was structured in a logical design, test, optimization and comparative evaluation format. Both glass/plastic (Type 1) and transparent ceramic/glass/plastic (Type II) armor vision block constructions were carried in competition throughout the program at a common threat level (Figure 1). The most important objectives consisted of maximizing vision block visibility and armor piercing ballistic defeat capability, in that order. Additional objectives consisted of ensuring the produceability and in-service durability of the improved vision blocks.

The best designs of each of the competing armor constructions subsequently were fabricated into prototype military configuration vision blocks (Figure 2). A series of rigorous optical, ballistic, and environmental tests were conducted on these configured test articles. An important

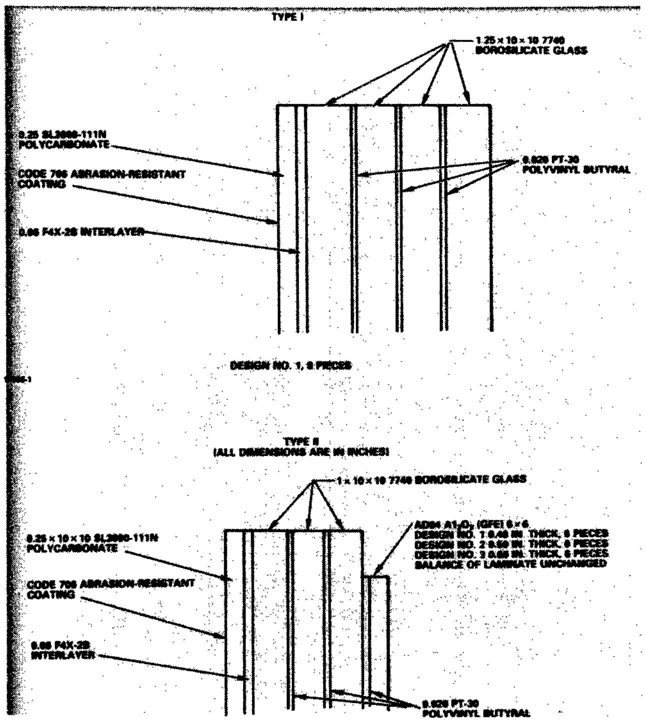


Figure 1

objective was to obtain sufficient data by the conclusion ot work to permit a critical comparative review of optical properties, projected cost, areal density, and thickness factors. This review would identify the armor construction of highest merit offering protection at the design threat level.

The Phase I work effort consisted of the following sequential tasks:

- Analysis of threat level specified by the Army Materials and Mechanics Research Center (AMMRC) and existing transparent armor data base
- Preliminary design consisting of the selection, gauging, and geometric arrangement of materials
- Preparation and forwarding of preliminary design test laminates to AMMRC for ballistic testing
- Vision block design optimization
- Preparation and forwarding of optimized design test laminates to AMMRC for verification ballistic testing
- Program review meeting.

Threat Level and Ballistic Data Review

A review of the threat level specified by AMMRC for the program was conducted. A search of available sources of glass/plastic and transparent ceramic/glass/plastic armor

ballistic data failed to disclose useful information for the specified threat. This lack of data necessitated the utilization of both opaque armor data at the design threat level and the extrapolation of lesser armor piercing threat data.

Preliminary Test Laminate Design

Using the best available information from the threat level review and data search, preliminary designs of glass/plastic and transparent ceramic/glass/plastic were established by mutual agreement between Goodyear Aerospace Corporation and the AMMRC technical supervisor. These designs were identified as Type I (glass/plastic) and Type II (transparent ceramic/glass/plastic) for categorical identification throughout the program.

The preliminary laminate designs established consisted of one Type I and three Type II configurations. Borosilicate glass was selected for both the Type I and II designs. It possesses the following advantages:

- High luminous transmittance
- Water-white appearance
- Higher hardness than soda-lime glass
- Lower density than soda-lime glass
- Commercial availability in very thick section.

A SL3000-111N-grade General Electric Company, polycarbonate sheet Lexan, was selected for the following reasons:

- High luminous transmittance
- Light straw color
- Best optical quality.

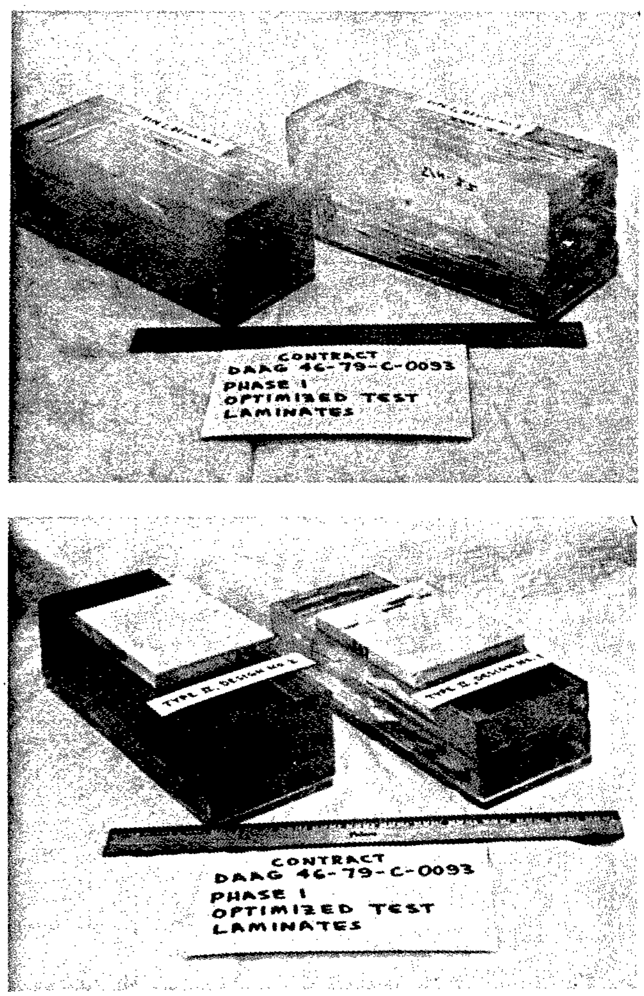


Figure 2

Preliminary Test Laminate Fabrication

All ceramic plates required were Government furnished equipment (GFE) provided to the program by AMMRC. Opague Coors AD94 aluminum oxide was used as the facing plies on all Phase I, Type II test articles for reasons of cost. The opaque AD94 ceramic has approximately the same hardness and ballistic capability as the transparent ceramic used in the Phase II configured vision block test articles.

Preliminary Test Ballistic Testing

The Type I and II preliminary test laminate specimens were ballistically tested at AMMRC on 16 January and 24 January 1980. At the conclusion of testing, the test specimens and the ballistic data were carefully studied by the AMMRC technical supervisor and the Goodyear Aerospace Corporation project engineer during a design review meeting. Assessments by those participating in the meeting were based on optical properties, ballistic performance, material costs, manufacturing economy and weight factors. The meeting resulted in the establishment of two each of the Type I and II optimized vision block laminate designs by mutual agreement.

Optimized Test Laminate Fabrication

Eight each of the two Type I and six each of the two Type II optimized laminate designs were fabricated. The Type I and II optimized test laminates were ballistically tested at AMMRC in late April, 1980. A program review was conducted with joint AMMRC/Goodyear Aerospace

Corporation participation on 23 April 1980. The ballistic data was used in conjunction with optical quality and fabrication assessments to define the final Type I and II laminate designs for Phase II work effort.

The Phase II work effort consisted of the following sequential tasks:

- Fabrication of 12 each Type I (glass/plastic) and II (transparent ceramic/glass/plastic) military configuration vision blocks
- Optical test evaluation of the vision blocks
- Environmental testing of the vision blocks
- Ballistic testing of the vision blocks (Figure 3)
- Preparation of engineering drawings for the Type I and II vision blocks.

The Phase II work effort consisted of the following sequential tasks:

- Fabrication of 12 each Type I and II military configuration vision blocks
- Optical test evaluation of the vision blocks
- Environmental testing of the vision blocks
- Ballistic testing of the vision blocks
- Preparation of engineering drawings for the Type I and II vision blocks.

Prototype Vision Block Design

The prototype transparent vision blocks fabricated in Phase II were designed to incorporate the geometric ply arrangements and component scaling in accordance with the final Type I and II designs selected at the conclusion of Phase I. The overall length of ten of the Type II vision blocks was reduced to accommodate the present state of the art of aluminum oxide producibility.

Goodyear Aerospace Code 706 abrasion resistant coating was specified to protect the inner surface of the polycarbonate ply on both Type I and II designs. This coating is used on all production transparent armor made by Goodyear Aerospace. It significantly increases the abrasion and chemical resistance of the material.

Goodyear Aerospace Code 806 sealant was specified for the filler which bonds the laminated vision block in the metal case. This sealant has a low modulus of elasticity and an extremely low rate of moisture permeability.

Engineering reproducible drawings were prepared for vision blocks of both Type I and Type II designs in accordance with MIL-D-1000A, Level 3 (Production). A total of 12 each Type I and II prototype vision block assemblies were fabricated in accordance with the production drawings.

One material substitution was made during the fabrication of these parts. Goodyear Aerospace Code F6X-2 sheet interlayer replaced the SR-41 PVB in bonding the transparent ceramic face ply to the glass, and the F4X-2B cast in place interlayer to bond the polycarbonate back ply to the glass.

Typical laminated transparent vision block and metal case components prior to assembly are shown in Figures 4 and 5. The completed assemblies together with a standard vision block are shown in Figure 6.

Ballistic Testing

Eight each of Type I and II prototype vision blocks were shipped to AMMRC for ballistic testing at the design threat level. Goodyear Aerospace designed and fabricated holding fixtures to support this effort. The fixture made from 1/2 inch thick MIL-A-12560D (MR) armor steel plate featured a bolted replaceable top plate and adapting shims for mounting the shorter Type II test articles. The holding fixture simulated the hull of an armored vehicle to secure the vision block assembly upon projectile impact (Figure 3).

Environmental Testing

Four each of Type I and II prototype vision blocks were subjected to a series of environmental tests intended to impose rigorous demands on the designs in recognition of the intended military usage. All eight test articles were conditioned during each test, and the same parts underwent all of the test exposures. Visual examination of each test article was made at appropriate times throughout the various conditioning modes. Each part also was examined carefully at the completion of each specific test. Control optical tests were made prior to the start of the environmental test conditioning.

Following the completion of the environmental testing, all prototype vision blocks were retested for optical properties. A comparison of original and post-test values was used to determine the changes, if any, created by the conditions imposed.

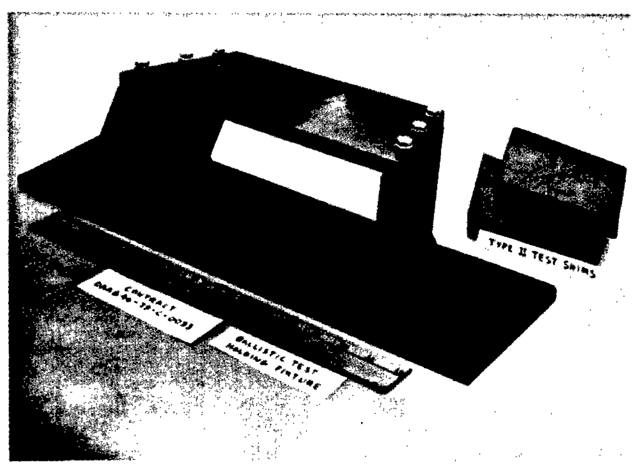


Figure 3

Test Descriptions

The optical and environmental tests utilized to evaluate the durability of the prototype vision block designs are described in the following paragraphs. Comments regarding the manner in which the test articles withstood these conditions are included.

(1) Unexposed Control Optical Tests

Luminous Transmittance values were determined in accordance with Federal Test Method No. 406, Method 3022. A Gardner Laboratory Model XL-230 Colorimeter was used for this test.

Haze values were determined using the same procedure and apparatus described for luminous transmittance.

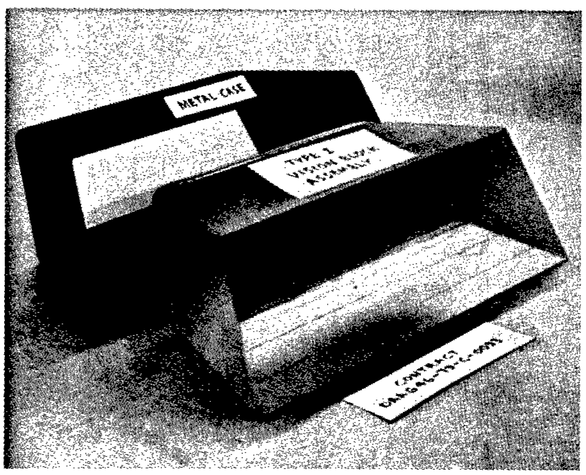


Figure 4

Optical Distortion through each test article was determined by direct measurement of grid line slope from photographs. The procedure, in accordance with MIL-G-5485C, consists of photographing an optical test grid board through the vision block. The test grid is made of accurately positioned fine white lines crossing to form a pattern of 1 inch squares on a black background. The first test articles of each type were evaluated using the double exposure photographic technique. This superimposes the reference grid over the grid as seen through the vision block.

An examination of the first double exposure photographic records showed virtually no optical distortion. Some optical deviation (apparent parallel displacement of grid lines) was evident, due to the

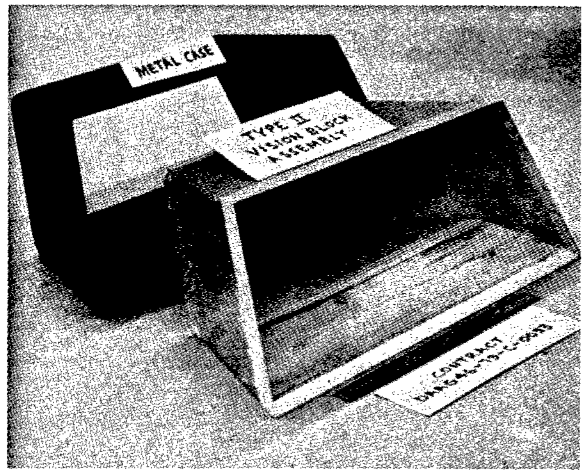


Figure 5

camera lens viewing through the appreciable thickness of the vision block. The displaced grid lines created a very busy record. After visually examining the remaining test articles and finding negligible distortion, it was decided to use single exposure photographs to provide a cleaner record.

(2) Environmental Test Evaluation

High Temperature testing was done in accordance with MIL-STD-810C, Method 501.1, Procedure 1. The high temperature test is intended to determine the resistance of equipment to evaluated

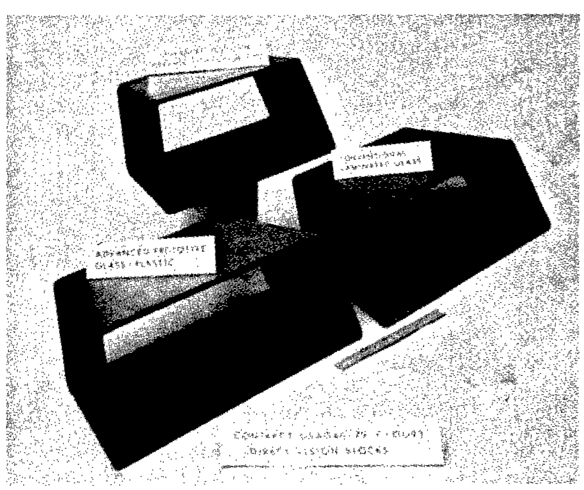


Figure 6

temperatures that may be encountered during service life either in storage or under service conditions.

The post-test inspection disclosed the following changes in the test articles:

- Small areas of delamination of the GACA Code 806 adhesive sealant to the glass and polycarbonate vision block surfaces were visible on all four Type I test articles. These delamination were estimated to include from less than one percent to a maximum of five percent of the total bonded area for the various test articles. The integrity of the laminated vision block transparency remained intact.
- Similar small areas of Code 806 adhesive sealant delamination to the glass and polycarbonate surfaces were noted for the Type II test articles. In addition, nearly all of the Code 806 bond to the edge of the transparent ceramic face ply had delaminated on all four parts.

Very slight edge and corner delaminations of the GACA Code F6X-2 interlayer bond to the transparent ceramic face ply were also visible. These delaminations, located primarily in the lower corners of all four parts, did not exceed approximately 0.05 inch encroachment into the laminate.

Low Temperature testing was conducted in accordance with MIL-STD-810C, Method 502.1, Procedure 1. The low temperature test is intended to deterine the effects of low temperature on equipment during storage or in service. The post-test inspection disclosed no changes in the condition of the test articles except for the following:

- One additional very small area of GACA Code 806 adhesive sealant delamination to glass on three of the four Type I test articles. These delaminations did not exceed 0.1 square inch each.
- One similar size GACA Code 806 bond delamination to glass on two of the four Type II test articles.

Temperature Shock testing was conducted in accordance with MIL-STD-810C, Method 503.1, Procedure 1. The temperature shock test is intended to determine the effects on equipment of sudden changes in temperature of the surrounding atmosphere. One of the most common causes of such rapid changes in the military environment is associated with rapid altitude changes during air transport of equipment.

Post-test inspection of the test articles revealed no change in condition for any part except the Type II, S/N 8 item. The outer ply of borosilicate glass (directly behind the transparent ceramic face plate) developed a fracture in the lower corner. The fracture probably resulted from a small, undetected defect on the edge of the glass.

Humidity testing consisted of exposing the test articles for 10 days at 160 deg F and 37 percent relative humidity under steady state conditions. The test specimens were examined daily throughout the exposure period. After four days of exposure, small delaminations of the F6X-2 interlayer bond to the polycarbonate back ply were visible on the Type I, S/N 2, and S/N 4 articles. By the fifth day of exposure, the S/N 2 vision block delamination had increased. The S/N 4 article delamination appeared to be unchanged in size. No delamination or other degradation was observed on the remaining two Type I or the four Type II test articles. At the conclusion of the 10 day exposure period, the test articles were returned to standard ambient conditions and stabilized. All of the test articles were cleaned and visually examined.

The S/N 2 vision block delaminations had increased, as had the single delamination on the S/N 4 vision block, but no additional delaminations were visible on these two vision blocks and there was no evidence of degradation resulting from the humidity exposure on the other two Type I and all four Type II test articles.

The F6X-2 interlayer delaminations experienced on the two Type I vision blocks were not typical. The quality of the interlayer bond achieved on these articles is questionable. The dissimilarity of behavior between the two delaminating vision blocks and the other six test articles creates the suspicion that a contaminant was present during fabrication of the two parts. The contaminant could have been on either the polycarbonate surface or on the F6X-2 sheet interlayer. After concluding the post-test examination, all of the test articles were thoroughly recleaned and readied for the post-environmental test optical retesting.

(3) Post-Environmental Test Optical Retests

Following the completion of the environmental test series all eight test articles were retested for luminous transmittance and haze in accordance with the original test procedures. All eight test articles were reexamined at the optical test grid board for distortion. No visual change was evident in any of the parts. The rephotographing of the test assemblies was waived due to the lack of observed distortion worthy of documentation.

(4) Disposition of Environmental Test Articles

After concluding the post-test evaluation of the

environmental test articles, all eight parts were delivered to AMMRC for ballistic testing.

Significant Potential for New Designs

The feasibility of designing and producing direct vision type vision blocks which offer very significant improvements in operating personnel visibility and ballistic protection has been demonstrated and the improvements can influence the operational and survivability aspects of armored vehicle performance. Further, the utilization of the improved vision blocks will be most applicable to lightweight, high performance armored vehicles such as the XM-2, XM-3, Commando Scout, Commando V-150 and MPG-NT Mobile Protective Gum.

These improvements also are beneficial to the entire inventory of more conventional armored vehicles, such as tanks, personnel carriers, and rocket system vehicles, particularly as they are upgraded in performance characteristics.

However, the most significant visibility gain potential lies in the application of the advanced transparent armor constructions to new vehicle designs. The higher level of ballistic capability offered by the improved designs will allow an increase in the vision block viewing area. Current vision blocks are very small to minimize ballistic vulnerability, since the transparent block sometimes has less ballistic defeat capability than the vehicle hull.

Within the current state of the art, the Type I glass/plastic design offers the best performance/cost tradeoff.

Contamination and Bonding Still Problems

Several aspects of the materials and manufacturing technology used to produce the prototype vision block assemblies must be improved. This effort is required to correct the deficiencies uncovered during the environmental testing. Specifically, improvements are needed in the following areas:

- Increased adhesion of the Code 806 sealant to glass and polycarbonate materials. The integrity of the sealant bond which joins the vision block and case must be maintained during environmental conditioning.
- Increased awareness of contamination potential and its effect on the resultant interlayer bond. The bonding substrates must be adequately cleaned, and this state must be maintained until the composite is assembled and the bond achieved. The sheet interlayer must be produced free of contaminants and must be stored in packaging and environments which do not add contaminants prior to its use.

Scratch Resistant Coating Needed

A need exists for an improved hard coating to protect the exposed inner surface of the armor composite polycarbonate component. The present state of the art in abrasion resistant coating adds chemical resistance, and also prevents damage to the inner vision block surface during routine cleaning operations. The success of the present coating relies on careful attention to the cleaning procedure, which requires air blast and water flooding techniques to remove abrasive particles. The coating can be marred by gross abrasion or sharp objects. The durability of the coating in the severe operational and maintenance environment of military vehicles has not been proven. A truly scratch resistant coating for polycarbonate should be developed and incorporated into high performance glass/plastic vision blocks to add to their service life.

Field Trials and New Designs Beneficial

Two types of armored Army vehicles which have direct vision type vision blocks should be selected for use in field trials of the improved design articles. One vehicle should be either an armored personnel carrier or tank of the latest design, while the second selection should be a high performance, lightweight, armored reconnaissance vehicle.

The complexity of this field trial program should be minimized by designing direct replacement configuration improved vision block articles for both vehicles. This action will preclude the need for vehicle modifications and permit comparisons to be made of the merits of standard versus new vision blocks unaffected by size or configuration factors. A comprehensive field test plan should be preparred to define the scope, conduct, and assessment criteria for this effort.

Also, a design review should be made of all currently operational direct vision type vision block installations in Army armored vehicles. Present designs should be analyzed and categorized by form and function. New designs incorporating the improved vision block construction should be prepared for retrofitting current vehicles. This would be a more formal engineering effort than the activity supporting the fabrication of the prototype vision blocks for the two vehicle field test. Improvements in the design of the vision block installation and casing techniques should be sought for functional and cost reduction reasons. The scope of this new design and retrofit activity would be dictated by the findings of the design review and Army requirements.

Affording A Low Cost Alternative

Composite Dies for High Energy Rate Forming

Development of medium life composite dies for forming stainless steel and titanium alloys has slashed costs in half and shortened lead time by at least as much compared to conventional dies. This milestone was marked by the successful completion of a manufacturing technology program for the U.S. Army. A 10 month development program for the Army Materials and Mechanics Research Center was conducted by Hughes Helicopters to design, fabricate, and test/evaluate a low cost composite die system for high energy rate forming (HERF) of titanium and high temperature alloy parts commonly used on helicopters.

HERF Best Candidate

During several earlier years the manufacturing engineers at Hughes Helicopters had analyzed a number of methods for precision compound contour forming of fatigue resistant sheet metal. Four of the most promising methods investigated were as follows:

- Explosive forming (high energy rate forming—HERF)
- Stretch forming (shallow, open contours only)
- High pressure bladder (Verson-Wheelon typical)

ERNEST N. KINAS is a Mechanical Engineer, Prototype Development Division, Metals and Ceramics Laboratory, U.S. Army Materials and Mechanics Research Center. He has been active for over twenty-five years in metals research and development, specializing in process development and prototype processing. He is also extensively engaged in engineering investigation programs in high density kinetic energy armor piercing penetrator materials, atomic shell munitions, prototype ceramic forging dies, and prototype high strength metal-plastic laminates. He serves as a forging consultant to other Army organizations and represents the Army in Government committees and conferences on forging. He is a registered Professional Engineer and a member of American Society for Metals, the Project Management Institute, and the American Association for the Advancement of Science. He received his B.S. in Engineering from Northeastern University.

NOTE: This manufacturing technology project that was conducted by Hughes Helicopter thru the U.S. Army Materials and Mechanics Research Center was funded by the Aviation Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AMMRC Point of Contact for more information is Ernest Kinas, (617) 923-5270.

- Precision roll forming (constant section shapes)

Of the four methods listed, only explosive forming (HERF) appears to meet the requirement of consistent dimensional precision on a part to part basis at reasonable recurring manufacturing cost. In the past, explosive forming had two major disadvantages. One was the cost and long lead time required to obtain high strength steel dies. The other was the limitations imposed by the various State and Federal agencies on the use of explosives in a factory environment.

New Material for Die Construction

Prior to this developmental effort, Hughes reviewed and evaluated all known low-cost short lead time die forming fabrication concepts used in both the aircraft and other commercial industries. These concepts used the following materials for die construction: ice mixed with nonmetallic fibers and sawdust, Cerrobend (trade name), Kirksite (trade name), plastic—cast epoxy (trade name of Devon) and urethanes, plastic (face) with conventional concrete backup in a steel container, and aluminum—cast and finished machined.

None of these fabrication materials were considered structurally adequate to meet the low cost, short lead time. medium life design objectives for the composite die. The Hughes HERF die approach uses a hard (electrodeposited) nickel liner about 0.120 in. thick to provide a high strength, smooth die surface. The liner is backed up with chopped steel wire fiber reinforced concrete having the trade name Wirand. The concrete backup material is contained by a steel outer shell.

Soniform One Answer

As previously mentioned, two drawbacks to the use of HERF were cost/long lead time and the use of explosives in a factory environment. Hughes Helicopters uses a machine called the "Soniform" to perform electrohydraulic forming. This type of cold forming involves the very rapid release (approximately 20 microseconds) of electrical energy from a capacitor bank into a working fluid, usually water.

The Soniform (Figure 1 & 2) has a capacity of 150,000 joules at 20,000 volts and consists of the following main subsystems when HERF cold forming is done:

- A power supply that converts 440 volts to the preset charging voltage for the capacitor bank.
- A capacitor bank to store the electrical energy.
- A movable console that contains the following low voltage controls:

  —Hydraulic press control (open-close)

  —Die cavity vacuum pump switch
  —Water cavity fill and drain switches

  —Capacitor voltage level control

  —Capacitor charge switch.

- A transducer (containing two electrodes) to discharge electrical energy in the working fluid
- A power switch to connect the capacitor bank to the transducer
- A 200 ton hydraulic press
- A die system for shaping a specific part.

Operation of the machine is fully automatic once the capacitor charge switch is closed. First, electrical energy (in kilojoules) is stored in the capacitor bank at predetermined voltage. Then the capacitor charge switch is closed. When the capacitor voltage reaches the preset level, the power switch automatically closes, causing a high energy spark to occur at the gap between the transducer electrodes in the water cavity. This release of electrical energy causes the water in the vicinity of the electrodes to become ionized, thereby creating a very high pressure (50,000 psi) in this area. A high velocity hydraulic pressure wave is formed inside the water cavity and acts on the part to be formed. Since the die cavity has been evacuated of air by a vacuum pump, the part is forced at a high rate of speed (500-800 ft/sec) to conform to the shape of the die cavity. Because the part is permanently deformed beyond the elastic limit, it takes the shape of the die cavity.

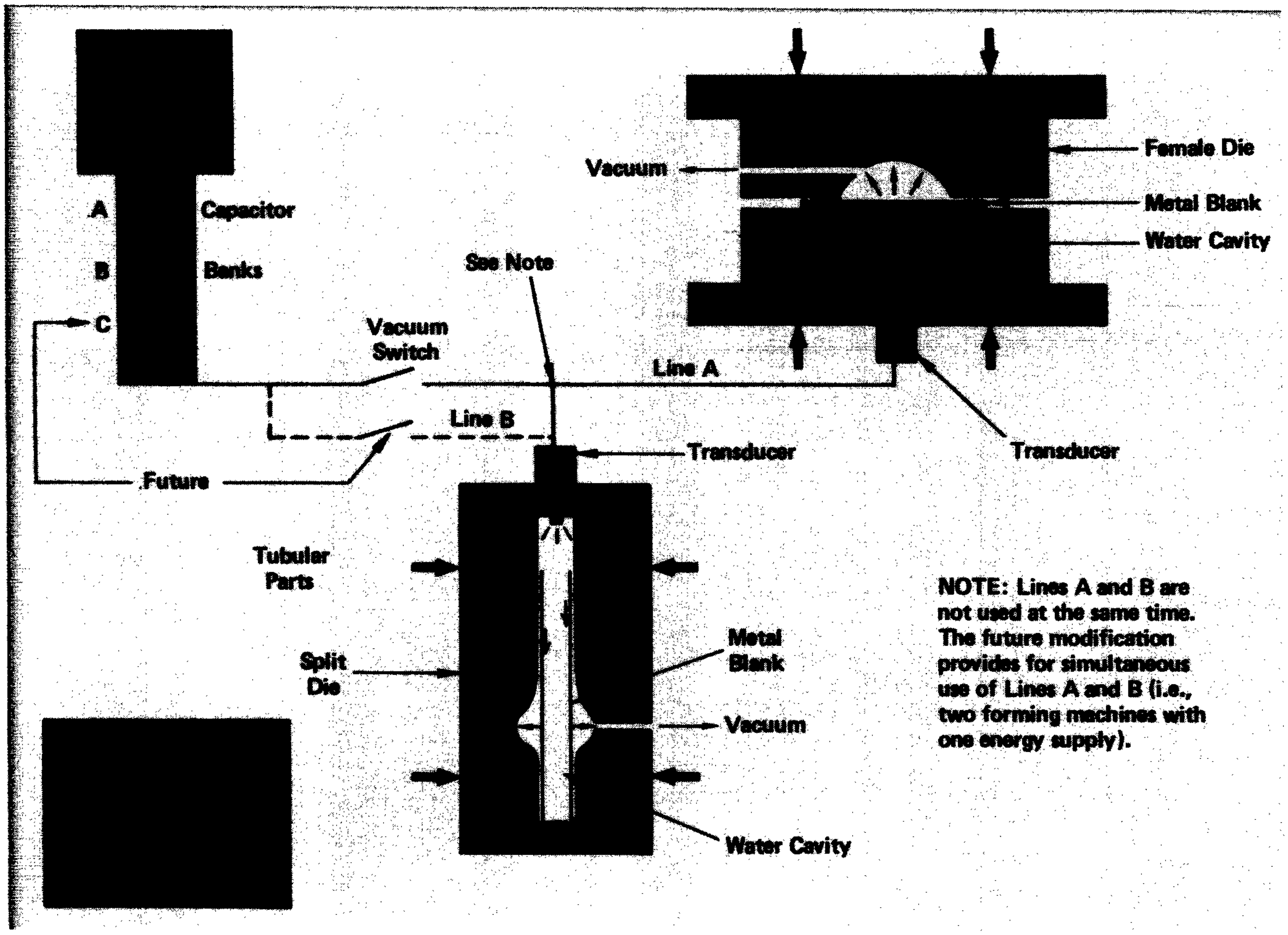


Figure 1

Forming Development

The two materials originally selected to evaluate the low cost composite die were N-155 and 6Al-4V titanium alloy. As permitted in the contract, 321 stainless steel was substituted for N-155 since it was cheaper and more readily available. (The two metals have equivalent forming characteristics.) The contract requirement for forming of five parts of each of the two selected materials was satisfied by using seven pieces of 321 stainless steel and eight pieces of 6Al-4V titanium alloy.

HERF operations, whether explosive or electrical discharge forming, usually require a few trial operations to develop the most efficient energy level per shot for maximum die life. In addition, a certain amount of time is

also required to "shake down" a new forming development with regard to loading and vacuum sealing a part in the die. Also, a die handling sequence must be developed for dies as heavy as the 2200-lb die used in this project.

In the first trial forming effort using a 321 stainless steel part, a slight bulge formed in the ribbed area of the die for an overall elongation of approximately 4 percent. A series of concentric wrinkles was formed in the weld area (approximately 8 in. circumference) of the part. Successive trials under varying conditions did not solve the problem. Upon review of the above forming results, it was decided to try another part with a series of shots at a much lower energy level. This approach proved to be completely successful. The four parts all formed net to the die with excellent shape detail. The parts are shown in the photograph presented previously as Figure 2. The parts actually formed so tight in the die that a wheel puller type of part extractor had to be developed to remove the parts.

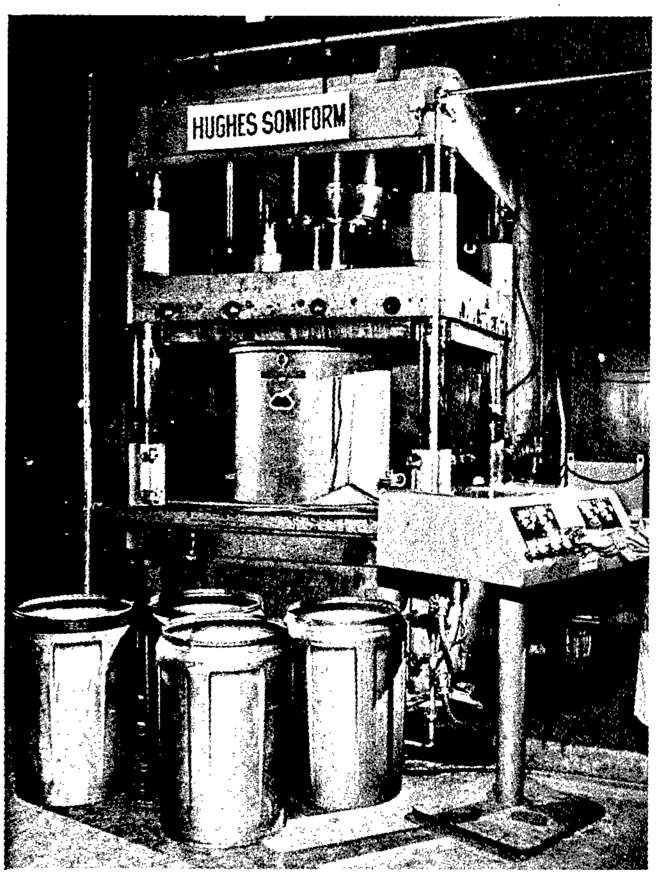


Figure 2

6A1-4V Titanium Alloy Forming

The contract required that five pieces of 6Al-4V titanium alloy be cold formed (using the HERF technique) on a best effort basis in the low cost die developed. Since cold forming of titanium to precise dimensions ($\pm$0.010 in. tolerance) is known to be pressing the state of the art, eight parts identical to the stainless steel parts were obtained for development of the forming parameters. Cold forming of the titanium alloy was approached very carefully in that the energy level was kept conservatively low for the first stage forming by holding the energy level below 20.0 kilojoules (14,752 ft-lb). However, this energy level proved too high, as one part failed (ruptured) on the fifth shot at 19.6 kilojoules (14,457 ft-lb). In order to develop an upper energy level limit versus the number of shots, a second part which had already been shot five times at 19.6 kilojoules was put in the die and shot once at 30 kilojoules (approximately a 50 percent increase). The increased energy level caused the part to rupture. After a careful analysis and review of the above die forming, a three stage forming schedule was selected.

An analysis was made to determine the cause of ruptures. It established that the failures were caused by the relatively sharp 0.172 in. radius of the ribbed section of the die cavity. This sharp radius created a notch effect which placed the material at such a high local stress level that the ultimate strength of the material was exceeded. The stress level of the unsupported (and incompletely formed) portion of the part must be kept in the yield region to permit the part to have complete forming (Figure 3). Figure 4 is a photograph of this part along with a formed 321 stainless steel part. This type of failure appears to be unique to high strength titanium alloys when they are subjected to cold forming (even though three stage forming is used).

HERF 49-55 Percent Cheaper

The development work performed under this project established that high energy rate forming of 321 stainless

steel can be readily accomplished using low cost, short lead time, medium life composite dies. Cost was 49 percent cheaper for parts fabricated and an estimated 55 percent cheaper for twice size parts. Lead time was estimated at half of conventional tool steel systems. As far as die life is concerned, 275 cycles were performed with no die deterioration. Estimated die life in excess of 500 cycles. Sizable cost savings can be realized when parts used in this project are cold formed by HERF in a composite die. Die life of 2,000 cycles (medium run) should present no problem. Also, as more experience is gained with composite dies, the desired short lead time of one third of conventional die systems should be readily obtainable.

In the design of composite dies, careful consideration should be given to the die vacuum provisions to ensure trouble free, low cost production. For example, the O-rings and gasket material used to seal the die cavity should be readily replaceable in the event that they are damaged during a part insertion or extraction.

Cold forming of 6Al-4V titanium alloy by any method (HERF or conventional) will be compromised with regard to repeatable dimensional accuracy of the formed part due to the metal spring back variation on a part to part basis. Still other limitations are the low elongation possible with titanium as compared to stainless steel and the rapid work hardening of titanium when formed, which can lead to premature rupture of the part.

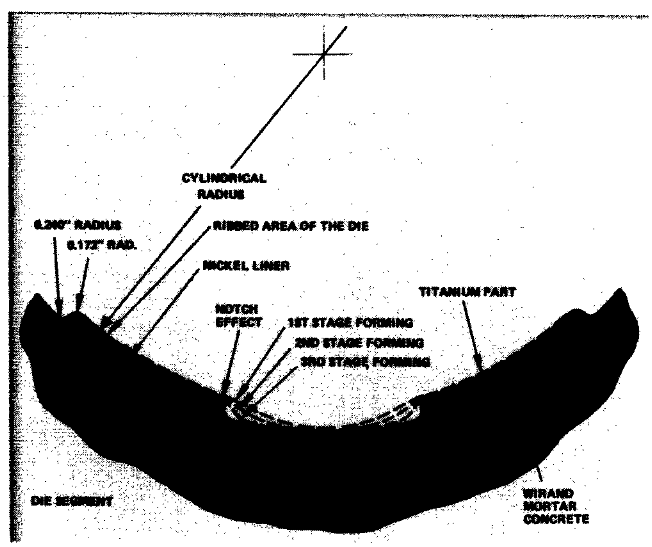


Figure 3

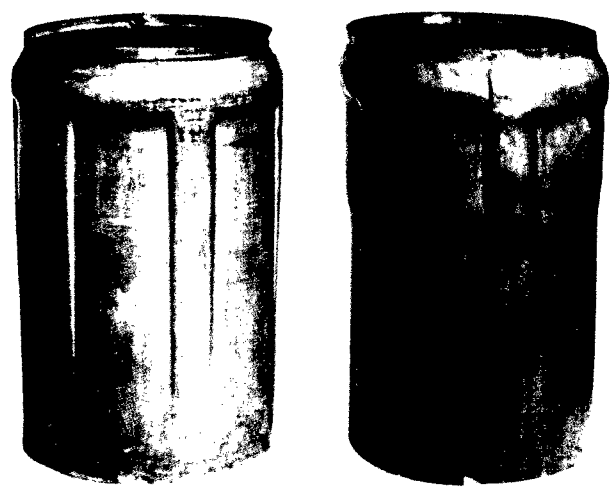


Figure 4

Twofold Work Needed

The successful developmental work completed under this project should be continued in a new twofold project:

- First, a low cost composite die should be fabricated to permit HERF cold forming of a relatively large, current production part such as the OH-6A engine access door (left and right hand parts fabricated simultaneously). The recorded costs, lead time, and die life using the new fabrication technique then could be compared to actual costs, lead time, and die life established for the conventional stretch-form method. In other words, the HERF low cost die system would be subjected to a "real world" comparison.

- Second, a detailed feasibility study should be made to determine the practicality and cost of cold forming a very large part using the out of press incremental forming concept. A proposed facility using this concept has been considered.

Brief Status Reports

Project 7412, AVRADCOM. Infrared Detector for Laser Warning Receiver. Perkin-Elmer Corp. Electro Optics Division is conducting production engineering on methods for making, assembling, and testing interdigitated IR detectors. Indium arsenide material suppliers were qualifid. Will be for AN/AVR-2 IR detector for use aboard aircraft. Masking, photolithographic, etching and bonding were used. Final status report received. For additional information, contact F. Reed, AVRADCOM, (314) 263-1625.

Project 1021, MICOM. CPPP Machined Cylindrical Parts (CAM). This project is complete. A computer managed process planning system has been developed and is currently being used at three companies. The system has been applied on two military aircraft engines. Final status report received. For additional information, contact R. Kotler, MICOM, (205) 8876-2065.

Project 1023, MICOM. Digital Fault Isolation F/Hybrid Microelectronic Modules. Hughes developed an automatic back trace and probing method to detect digital failure in hybrid circuits. DTS-70 test aid and fast race software acheived .94 comprehension. GD/ND-GD test is performed in 5 sec. system to be implemented at Hughes Tucson GDCD. Final status report received. For additional information, contact G. Little, MICOM, (205) 876-3604.

Project 1024, MICOM. MMT Radio Frequency Stripline Hybrid Components. Hughes developed a model of beam lead varactor diodes used in a frequency doubler. Thin dielectric sheet suspender substrate was used to match inpedance of diodes and wave guides. Dielectric thickness kept at .005 in. min. Diodes are reflow soldered. Final status report received. For additional information, contact L. Woodham, MICOM, (205) 876-4948.

Project 1050, MICOM. Low Cost Braided Rocket Motor Components. This project has been completed successfully. The Interim Tech Report, RK-CR-82-6, has been distributed. Final status report received. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 1086, MICOM. Cobalt Replacement in Maraging Steel-Rocket Motor Components. This Phase I technical effort is complete. Technical Report RK-CR-83-1 is disttributed. Phase II continuing. Final status report received. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 3516, ERADCOM. Cryogenic Cooler Hybrid Motor Circuit. Aeroflex completed its hybrid circuit work and documented it in a TV tape shown at the electronics minisymposium at MTAG 82. Final technical report received from Aeroflex. Circuit may be used in Stirling cooler for AN/TAS=4. For additional information, contact S. Horn, ERADCOM, (201) 544-4258.

Project 9813, ERADCOM. Ruggedized Low Cost Quadrant Detector for CLGP. Negotiated termination of TI contract has been completed. Martin-Marietta can meet all future Copperhead quadrant detector requirements. TI could not overcome sodium poisoning of silicon detector. Final status report received. For additional information, contact M. Skeldon, ERADCOM, (201) 544-4259.

Project 1026, MICOM. Production of Low Cost Missile Vanes. This project is complete. It was demonstrated that a composite missile vane can be manufactured and that automated production is feasible. The project was recognized throughout industry as a significant accomplishment. Final status report received. For additional information, contact E. Croomes, MICOM, (205) 876-7317.

Project 9835, CECOM. Integrated Thin Film Transistor Display. Aerojet found that present technology will not permit laying down multiple layers of display and driver films. Hybrid construction was used to build demo units. Rough surface is not suited for subsequent films. Final status report received. For additional information, contact M. Miller, CECOM, (201) 544-5205.

Project 3294, MICOM. Production Processes for Rotary Roll Forming. The interim technical report for this first phase is complete. Phase two is proceeding. Final status report received. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 3396, MICOM. Injection Molding of Low Cost One Piece Nozzles. Eighty MLRS nozzles were molded from six materials. Acceptable parts were made from four of those materials. Processing specs and QA requirements were prepared. Facility implementation costs were estimated. This facility could produce 120 per day. Final status report received. For additional information, contact W. Crownover, MICOM, (205) 876-5821.

Project 7338, AVRADCOM. Composite Tail Section. this project continuation was cancelled. Funds were

reprogrammed. A final technical report has been received which summarizes the effort (FY 79, 80, and 81 projects). For additional information, contact G. Gorline, AVRADCOM, (314) 263-1625.

Project 7183, AVRADCOM. Semi-Auto Comp Manufacturing Systems for Helicopter Fuselage Secondary Structures. The contract was terminated. A final report has been received. For additional information, contact G. Gorline, AVRADCOM, (314) 263-1625.

Project 7338, AVRADCOM. Composite Tail Section. This program has been terminated. A final report has been submitted. For additional information, contact G. Gorline, AVRADCOM, (314) 263-1625.

Project 7371, AVRADCOM. Integrated Blade Inspection System (IBIS). Final software debugging is presently being accomplished in preparation for a scheduled end of contract briefing. Final status report received. For additional information, contact G. Gorline, AVRADCOM, (314) 263-1625.

Project 1121, MICOM. Missile Manufacturing Productivity Improvement Program. Rockwell and Martin Marietta reviewed their HELLFIRE facilities and prepared Phase I final reports. Proposals for Phase II were received at MICOM and are being evaluated. Follow-on activities were postponed by HELLFIRE project office. Final status report received. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3165, MICOM. Production Process and Techniques for Sealing Hybrid Microcircuit Pack. M&K Associates, Solid State Equipment, and Huntsville Microcircuits provided a system for baking, parallel seam welding, and gross leak testing of hybrid packages. System is capable of sealing and leak testing hybrid packages at rate of 100 per hour with 95 percent yield. Final status report received. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3396, MICOM. Injection Molding of Low Cost One Piece Nozzles. Eighty MLRS nozzles were molded from six materials. Acceptable parts were made from four of those materials. Processing specs and QA requirements were prepared. Facility implementation costs were estimated. This facility could produce 120 per day. Final status report received. For additional information, contact W. Crownover, MICROM, (205) 876-5821.

Project 3435, MICROM. Simplification of High Power Thick Film Hybrids. Westinghouse reduced materials costs for logic substrates by 50% with reworkable backing lay/ solder system for substrate to header attachment. Capability for bonding aluminum wires up to .020 inch diameter was established. Final status report received. For additional information, contact L. Woodham, MICOM, (205) 876-4948.

Project 3453, MICOM. Ground Laser Locator Designator Production Improvements. Crystal technology has completed all contractural work resulting in production processes capable of 250 lithim niobate Q-switches per month. The Q-swithces have qualified for use by most U.S. manufacturers of military ranging and designator systems. Final status report recieved. For additional information, contact R. Kotler, MICOM, (205) 876-2065.

Project 5019, TACOM. Storage Battery Low Maintenance. Battery requirement and basic design of storage battery established. Contrac for prototype batterie sinplastic on-

Project 5019, TACOM. Storage Battery Low Maintenance. Battery requirement and basic design of storage battery established. Contract for prototype batteries in plastic containers completed and batteries delivered to TACOM. Effort continuing. Final status report received. For additional information, contact J. Reinman, TACOM, (313) 574-6492.

Project 4064, ARRADCOM. Auto Lap Operations for 105 MM Tank Cartridges. A production system for the automated load and assembly of a family of 105 MM tank cartirdges has been designed. Technical data for the liner to case assembly is available. A technical report will be available. Final status report received. For additional information, contact K. Lischick, ARRADCOM, (201) 724-4162.

Project 4444, ARRADCOM. Body for M42/M46 Grenade. Worl completed awaiting final technical report. Final status report received. For additional information, contact W. Field, ARRADCOM, (201) 724-4422.

Project 4466, ARRADCOM. Evaluate TNT, Cyclotol, Dotol inMelt-Pour Facility. Project complete. Final technical report will be distributed upon publication. Final status report received. For additional information, contact L. Manassy, ARRADCOM, (201) 724-2545.

Project 7807, ARRADCOM. Programmed Optical Surfacing Equipment and Methodology (CAM). A Bostomatic CNC milling machine has been adapted for grinding and polishing of optical surfaces (all on one machine). In addition, a milling machine interpretive language, which permits complex movements or whole operations was developed. Final status report received. For additional information, contact N. Scott, ARRADCOM, (201) 724-6945.

Project 4480, ARRADCOM. High Speed Head Turn Too. Mod F/SC AMMO Products. A complete set of improved headturn modules were purchased and installed. They are performing satisfactorily and have increased the tool module performance to over 41,000 pieces between adjustments. Final status report received. For additional information, contact M. Leng, ARRADCOM, (201) 724-5688.

Project 6774, ARRADCOM. Manufacturing Methods for APDS Projectile. Process studies were completed and the equipment designed. A molding system, utilizing a four cavity mold, and a trim station were fabricated. Demonstrations were completed at the vendors facility and the equipment was shipped to Ford Aerospace. For additional information, contact J. McCormick, ARRADCOM, (201) 724-4581.

Project 6774, ARRADCOM. Manufacturing Methods for APDS Projectile. The equipment was assembled and sample projectiles were submitted for ballistic testing. Testing was performed over the full temperature range with satisfactory performance. This project resulted in immediate saving of $235K. More with late buys. Final status report received. For additional information, contact J. McCormick, ARRADCOM, (201) 724-4581.

Project 4462, ARRADCOM. Forced Air Dry for Multi-Based Propellants. All work has been completed and the final technical report published. For additional information, contact A. Graff, ARRADCOM, (201) 724-3637.

Project 4411, ARRADCOM. Small Caliber Ammunition Process Improvement Program. Four separate circuit boards were consolidated into one on the primer insert SM. Bullet and case feeder efficiency increased from 85 to over 98%. Prototype bearing and tool condition analysis system feasibility was demonstrated. Final status report received. For additional information, contact E. Rempfer, ARRADCOM, (201) 724-3737.

Project 0915, ARRADCOM. Group Technical Requirements Definition Electronics. This project is complete. The fundamental characteristics of a group technology electronics classi fication/coding system have been developed. Final status report received. For additional information, contact N. Scott, ARRADCOM, (201) 724-6945.

Project 7963, ARRADCOM. Group Technology for Fire Control Parts and Assemblies. A pilot group technology system for fire control machined parts was completed. A microcomputer group scheduling program was developed. A final technical report is available. For additional information, contact N. Scott, ARRADCOM, (201) 724-6945.

Project 8001, ARRADCOM. Rapid Flow Plating of Small Caliber Gun Tubes. This project is complete. Smooth, adherent chromium can be electroplated inside the bore of 50 caliber gun barrels by the rapid flow plating process. The rate of deposition was about 15 times that for conventional plating. Final status report received. For additional information, contact V. Lakshminarayana, ARRADCOM, (201) 724-5746.

Project 7339, AVRADCOM. Filament Wound Composite Flexbeam Tail Rotor. All funds were withdrawn and reprogrammed. The project was terminated after the AAH-PM decided not to fund the design alterations and testing necessary for flight qualification because of the high costs involved. Final status report received. For additional information, contact Gerald, Gorline, AVRADCOM, (314) 263-1625.

Project 5024, TACOM. Gear Design, Manufacturing, Utilizing Computer Technology (CAM) Phase 2. This project is complete. The final report was distributed in February, 1983. Final status report received. For additional information, contact Dave, Pyrce, TACOM, (313) 574-6467.

Project 5064, TACOM. Lightweight Saddle Tank (Phase II). Fuel tanks for 5 ton vehicle underwent feasibility testing at Yuma Proving Grounds, cold region and tropic test sites, without failures. Deficiencies overcome by adding ribs (fillets) in tank and modifying corner radii. Final technical report issued. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 5067, TACOM. Plastic Battery Box (Phase II). Results show polyethylene is a durable material which will last the life of the vehicle. Re-

tainer exhibited cracks after dropping from a certain angle, but modification will correct the problem. Final technical report is being forwarded separately. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 5090, TACOM. Improved and Cost Effective Machining Technology (Phase II). All machining operations for Phase ii completed. Data has been computerized. An interim report has been written. A machineability handboo, will be published at the conclusion of Phase III. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 6054, TACOM. Advanced Metrology Systems Integration. This project was cancelled The remaining funds were diverted to another program. This effort will be resumed later. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 6100, TACOM. Engineering Support Directorate Technology Modernization Program. this project is complete. A scope of work for a comprehensive evaluation of the engineering support directorate was established. The results from the proposed work will provide a plan for technical modernization of design, test, and manufacturing capability. For additional information, contact Dave, Pyrce, TACOM, (313) 574-6467.

Project 3604, MERADCOM. Solid State Power Switch. CMOS devices came to market that meet the requirements of the SSPS. The CMOS devices proved simpler and more reliable. Project was discontinued. Final status report received. For additional information, contact F. Perkins, MERADCOM, (703) 664-5724.

Project 3604, MERADCOM. Solid State Power Switch. Considerable effort was expended in attempting to locate and solve the many problems encountered which prevented the SSPS from functioning properly. The FY78 + FY79 projects both were terminated without a satisfactory product. Final status report received. For additional information, contact F. Perkins, MERADCOM, (703) 664-5724.

Project 3717, MERADCOM. High Temperature Turbine Nozzle for 10 KW Power Unit. Project work was completed. Turbine nozzles were fabricated and will be tested in the follow-on Project 3717. Metal shrouds were fabricated and assembled with the nozzles. Final inspection and flow checks were completed. Final status report received. For additional information, contact J. Arnold, MERADCOM, &703) 664-5459.

Project 3745, MERADCOM. MMT Aluminum Skin-Graphite/Epoxy Sandwich Bridge Reinforcement. No work has been accomplished because R&D funds to develop the prototype material in support of this MMT effort were withdrawn to be used on higher priority R&D. This effort has been terminated. For additional information, contact E. Rudy, MERADCOM, (703) 664-5176.

Project 0001, DESCOM. Voice Controlled Programming of Computers. A voice input unit was linked with a CAD/CAM Graphics System at Tobyhanna Army Depot. The integrated system was demonstrated to be able to operate effectively, efficiently, and with little or no degradation to the graphics controller. Final status report received. For additional information, contact F. Estock, DESCOM, (717) 894-7099.

Project 7052, AVRADC(OM. Ultrasonically Assisted Cold Forming of Titanium Nose Caps. Equipment is modified and technical personnel are instructed in its use. Final status report received. For additional information, contact A. Ayvazian, AVRADCOM, (617) 923-5233.

Project 7340, AVRADCOM. Composite Main Rotor Blade. Project is completed. The effort is continuing. Final status report received. For additional information, contact J. Tutka, AVRADCOM, (314) 263-1625.

Project 7371, AVRADCOM. Integrated Blade Inspection System (IBIS). Final software debugging is presently being accomplished in preparation for a scheduled end of contract briefing. Final status report received. For additional information, contact B. Park, AVRADCOM, (316) 263-1625.

Project 7199, AVRADCOM. Surface Hardening of Gears, Bearings and Seals by Lasers. The final report has been published and distributed. The project was terminated since there was no logical course of action within the funds available. Final status report received. For additional information, contact R. Mulliken, AVRADCOM, (804) 878-2771.

Project 7284, AVRADCOM. Superplastic Forming/Diffusion Bonding of Titanium. Final technical report being drafted by Hughes Helicopter Company. Final status report received. For additional information, contact A. Ayvazian, AVRADCOM, (617) 923-5233.

Project 7286, AVRADCOM. High Quality Superalloy Powder Products F/Turbine Components. This is a joint Air Force & Army multiyear effort. GE has completed Items 7 and 9 of the effort which was funded under this project. Final report is under preparation. For additional information, contact S. Isserow, AVRADCOM, (617) 923-5504.

Project 7286, AVRADCOM. High Quality Superalloy Powder Products F/Turbine Components. This project supported in-house engineering for prior year (1797286) joint service effort. The prior year effort has been completed. Final status report received. For additional information, contact S. Isserow, AVRADCOM, (617) 923-5504.

Project 7338, AVRADCOM. Composite Tail Section. Due to funding caused schedule slippages, this program has been terminated. A final report has been submitted. Final status report received. For additional information, contact J. Tutka, AVRADCOM, (314) 263-1625.

Project 7298, AVRADCOM. High Temperature Vacuum Carburizing. This project has been completed. The process specification for AISI 9310 has been completed. BMS-7-223 and AISI 9310 Steel Test Specimens are being produced for test and evaluation of the vacuum carburizing process. Final status report received. For additional information, contact P. Fopiano, AVRADCOM, (617) 923-5327.

Project 7300, AVRADCOM. Improved Low Cycle Fatigue Cast Rotors. A dynamic similarity evaluation of the subject rotor concluded that all requirements could be met with existing tooling. Final status report received. For additional information, contact J. Lane, AVRADCOM, (804) 878-2771/3977.

Project 3708, MERADCOM. Coated Fabric Collapsible Fuel Tank-Circular Seam Weaving. This effort established the feasibility of producing seamless fabric suitable for collapsible fuel tanks. Coating of this seamless fabric with compatible polymer yet to be realized. Manufacturing technology continuing. Final status report received. For additional information, contact C. Browne, MERADCOM, (703) 664-5781.

Project × 7382, AVRADCOM. Low Cost Composite Main Rotor Blade for the UH-60A. Contract awarded to Sikorsky, preliminary design refinement, manufacturing compatibility studies, selection of blade configuration, and specimen tool design and fabrication has been completed. Blade external configuration same as current blade. Final status report received. For additional information, contact N. Calapodas, AVRADCOM. (804) 878-5732.

Project 5071, TECOM. Toxic Gas Measurements During Weapon Firings. Testing has been conducted using a nonportable toxic gas measuring unit in conjunction with a wind machine. The data obtained will be reduced and analyzed during the next phase of this task. Final status report received. For additional information, contact N. Pentz, TECOM, (310) 278-2375.

Project 5071, TECOM. Dispersion Data for Automatic Weapons at Long Range. Using data gathered during a literature search on the M240 machine gun and the squad automatic weapon system, it was determined that the long range dispersion for automatic weapons could be predicted based on short range dispersion data. Final status report received. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 5071, TECOM. Improved Engine Wear Analysis. Separation of suspended metallic particles in oil by filtration and centrifuging were investigated. A procedure based on column chromatography has been procured. Final status report received. For additional information, contact N. Pentz, (301) 278-2375.

Project 8053, NLABS. CADCAM of Parachute Hardware. Operational Feasiblity of the CAD/CAM software was established. Restructuring of the APT program is necessary for the system to become usable. A final report is available. For additional information, contact Frank Civilikas, NLABS, (617) 651-4883.

Project 3592, MERADCOM. Improved Graphite Reinforcement—Phase 3. Contractor task is completed except for preparation of final report. In-house portion of work to evaluate fiber strands and composites has begun. Contract for final phase of project is being processed. For additional information, contact F. Harris, MERADCOM, (703) 664-5471.

Project 7055, AVRADCOM. Ultrasonic Welding of Helicopter Fuselage Structures. Project terminated. Results of coupon testing of weld bonded specimens unsatisfactory. Final status report received. For additional information, contact R. Rodgers, AVRADCOM, (804) 878-5732/5476.

Project 7339, AVRADCOM. Filament Wound Composite Flexbeam Tail Rotor. Work is continuing on Phase III under a revised scope of work necessitated by funding constraints. All work is completed except the final report, which is in process. For additional information, contact S. Weisenberg, AVRADCOM, (314) 263-1301.

Project 7197, AVRADCOM. Fabrication of Integral Rotors by Joining. Pilot production successfully completed. Fracture mechanics data generation complete. Machining of rotors for spin test and engine test complete. Final status report received. For additional information, contact J. Pratcher, AVRADCOM, (314) 263-1625.

Project 7342, AVRADCOM. Pultrusion of Honeycomb Sandwich Structures. All work is completed. The effort is to continue. Final status report received. For additional information, contact N. Tessier, AVRADCOM, (617) 923-5172.

Project 7091, AVRADCOM. Processing Aircraft Components Using Pultruded Materials. All work has been completed. The final report has been approved and has been printed and distributed. The pultrusion and post-forming technique was successfully shown. Implementation is anticipated on future ACAP helicopter designs. Final status report received. For additional information, contact N. Tessier, AVRADCOM, (617) 923-5172.

Project 7342, AVRADCOM. Pultrusion of Honeycomb Sandwich Panels. The effort is continuing. Final status report received. For additional information, contact N. Tessier, AVRADCOM, (617) 923-5172.

U.S. Army ManTech at Work

The Army's Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, Va., has awarded a $4.82 million multiyear contract to a York, Pa. firm for the design and fabrication of a prototype heavy assault bridge. The experimental system, which will be built by Bowen-McLaughlin-York, will consist of a 100 foot span military load Class 70 bridge mounted on an M-1 tank chassis. The bridge will be designed utilizing composite materials for key components in order to reduce the system weight and reduce deflections.

Two New Systems Planned

A double-fold scissors design, the heavy assault bridge is one of two new bridging systems being developed by MERADCOM for the heavy and light divisions of the future. If the heavy assault bridge is ultimately accepted by the Army, it will replace the armored vehicle launched bridge currently in use.

Delivery of the prototype bridge is scheduled for March 1986. The command also recently awarded a four-year, $4.2 million contract to a Waltham, Mass. firm for prototypes for a 30 ton capacity light assault bridge. The technology for producing these bridge span systems was described in a feature article in U.S. Army ManTech Journal Vol. 7, No. 4, page 4.

MERADCOM is a major subordinate command of the U.S. Army Material Development and Readiness Command (DARCOM). The Fort Belvoir based organization employs more than 1200 military and civilian personnel who are involved in research, development, and initial acquisition in four areas that are critical to Army readiness: mobility/countermobility, survivability, energy, and logistics.

US Army ManTech Journal

Subtleties of Production

Volume 8/Number 3/1983

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Contents

ABOUT THE COVER:

High technology composite processing is shown in these two photograhs of developmental work under way at the U.S. Army Materials and Mechanics Research Center Composites Laboratory, Watertown, Massachusetts. The larger photo in the center shows a microprocessor controlled filament winding machine being used—in this case—for the automated production of ballistic specimens. It can be used to fabricate many different composite items. The smaller photographs are of a pultruder which is building a composite plank incorporating layers of preimpregnated composite tapes interspersed with metal tapes. The metal layers provide increased load spreading capability where structural composites require fastening at load bearing points. The equipment is flexible enough to accommodate many different types of prototype items. The insertion of metal layers can be intermittent as required at points of critical structural load characteristic to the part—without interrupting the production run. This feature is due to the use of a constant pressure (isobaric) die that is capable of expansion, forming laminates of widely varying thickness while maintaining constant pressure on the material flowing thru the die. For further information, contact Bernie Halpin, 617-923-5100. (Photos by John Corregio of AMMRC.)

THE MANTECH JOURNAL is prepared quarterly for the U.S. Army under the sponsorship of the Directorate for Manufacturing Technology, DARCOM, by the Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172, through the Metals and Ceramics Information Center, Battelle's Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201.

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Comments by the Editor


RAYMOND L. FARROW

The 15th Annual Conference of the Department of Defense Manufacturing Technology Advisory Group November 7–10 in Orlando, Florida will be hosted by the U.S. Army, at which key manufacturing executives from industry and the military services will meet to review past accomplishments and plan continuing efforts in this most vital program. We at the U.S. Army Materials and Mechanics Research Center are especially close to the planned activities of the conference, for we are charged with making all the arrangements for this annual meeting. This year is expected to be the most widely attended meeting to date, with over 800 participants. We are looking forward eagerly to handling the myriad of details that are entailed.

One of the special features of the meeting this year will be the videotaping of six minisymposia which will feature reports on projects of special significance. This first marks the Army's continuing dedication to provide the widest dissemination of manufacturing technology information for our nation's industrial base contractors, and it reflects the extent to which the Army will carry its responsibilities in support of this effort.

It is with regret that we learned of the retirement early in September of John Larry Baer from the Directorate of Manufacturing Technology at DARCOM. He has been a longtime associate and has been instrumental in structuring the current organization, which oversees the Army's mantech effort. He leaves the government service after 31 years of advanced materials work, having served at Picatinny and Frankford Arsenals and also at the U.S. Army Limited War Laboratory. He also served briefly as acting chief of the Office of Manufacturing Technology before the appointment of Darold Griffin to that post in early 1979. He will continue to be affiliated with the industrial base improvement effort as a consultant. We wish him the best of everything in his new role.

This issue of the U.S. Army ManTech Journal carries a brief outline of the agenda planned for the coming MTAG meeting in Orlando, at which manufacturing thrusts into the 1990's will be highlighted during the subcommittee meetings. These minisymposia will be videotaped and made available to attendees at a later date.

Several articles of special interest are featured in this issue, beginning with copper ampules for fuze power supplies, which discusses in detail the development and usage of an excellent process manual for the high speed manufacture of these items.

Integrated thin film transistor displays soon will be in production in a successful manner, as described in the second technical article in this issue. Further development following a pilot plant demonstration of a new process for their manufacture will make large-scale fabrication feasible. This project achieved its primary objective of establishing a successful pilot plant scale facility.

A significant new technique for postforming composite parts is detailed in the article on pultrusion adaptation. This new MICOM technology may open up whole new applica-

tions—as yet unforeseen—which will enable manufacturers to implement new cost savings in helicopter component fabrication. The full impact of this development is yet to be felt.

A dramatic new possibility for controlling NC machine tools thru voice recognition is the subject of the article on voice controlled computer programming. This remarkable development will hasten programming procedures for making parts by automation and also is expected to lessen the frequency of errors during input.

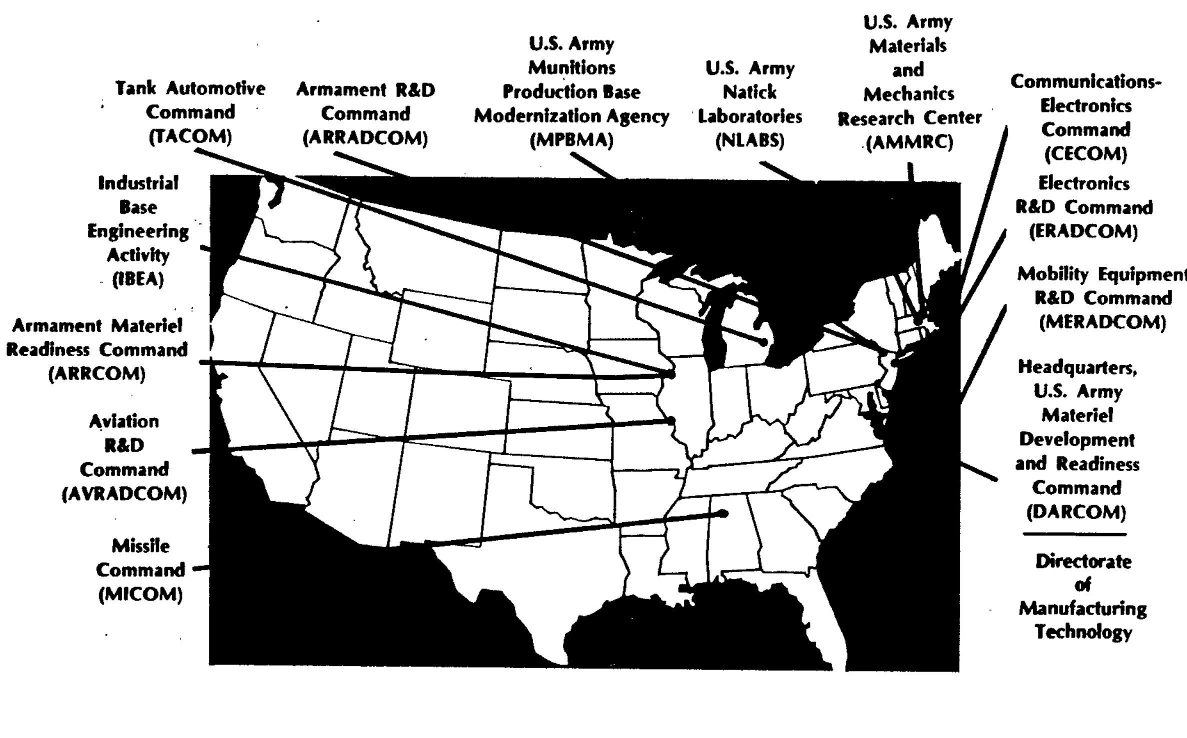
Our article on improved large armor steel castings outlines how the development of this technology could save considerable amounts of money over the cost of rolled welded armor fabrication normally used. Ballistic values also could be improved, with the possibility of further weight reductions in our armored vehicles.

Delidding and resealing of hybrid microelectronic packages can save enormous sums of money, as discussed in our article on page 28. Developing the capability to rework these hybrids can mean vast savings in labor and materials and can make possible the utilization of items that otherwise would have to be scrapped.

Real-time ultrasonic imaging can provide an essential and significant part of the production process—the evaluation of the quality of a production line item—especially when items having greater complexity of structural design are involved. This new development in ultrasonics imaging by Battelle-Northwest and General Dynamics could have far reaching impact during production of metallic or fiber laminate structures.

As has become our practice, the Army ManTech Journal again features a large number of up to date, brief reports of ongoing Army projects in a special seven page section at the end of the issue. These brief status reports always generate considerable response from our readers and will continue to be presented in future issues.

DARCOM Manufacturing Methods and Technology Community



Planning for the 1990's

15th Annual MTAG Conference Set

Organized for

The Directorate for Manufacturing Technology
DARCOM

by

The U. S. Army Materials and Mechanics
Research Center
Watertown, Massachusetts

Future manufacturing technology thrusts, including new concepts in manufacturing science, producibility, and R & D partnerships, will be emphasized during the 15th Annual Department of Defense Manufacturing Technology Advisory Group Conference at the Orlando-Hyatt in Kissimmee, Florida, November 7-10.

The U. S. Army, acting as host on behalf of the Department of Defense, has arranged the presentation of the largest number to date of exhibits on recently completed mantech projects. The Army expects these exhibits to further stimulate interest and provide the broadest possible dissemination of information on ongoing efforts to enhance our national production base.

MINISYMPOSIA TO BE VIDEOTAPED

This meeting will bring together the nation's manufacturing executives and technical specialists to review the progress and plans of the Department of Defense program for improving the productivity and responsiveness of the defense industrial base.

Highlights of the conference include six minisymposia to be conducted all day Wednesday, November 9 and halfday on Thursday, November 10:

- CAD/CAM
- Electronics
- Metals
- Munitions
- Nonmetals
- Test and Inspection.

These minisymposia will be coordinated by the six technical subcommittees of the Manufacturing Technology Advisory Group, and, for the first time, each will be videopated in order for the Army to widen dissemination of this up to date, comprehensive, state of the art information to all segments of our national production base.

FUTURISTIC THEME USED

Theme of this year's conference is "Planning for the 1990's", with the keynote address to be given by General Donald R. Keith, Commanding General, U. S. Army Materiel Development and Readiness Command. Guest speaker for the Tuesday night banquet will be James A. Baker, Executive Vice President and Sector Executive, Technical Systems, General Electric Company.

Arrangements for this year's conference are geing handled by the Army's Materials and Mechanics Research Center, Watertown, Massachusetts. Specific questions concerning this conference should be directed to David Seitz (617)923-5527.

High Speed Process Now in Use

Copper Ampules for Fuze Power Supplies

By
Andrew Sabonis, Jr.
Harry Diamond Laboratories
U. S. Army

Increased safety from damage of fuze power supplies due to dropping, plus the generation of a most comprehensive systems manual are the results of a new manufacturing process for making copper ampules. A high speed, semi-automatic production method was developed by Union Carbide's Battery Products Division for the manufacture of copper ampules for the Army Electronics Command's Harry Diamond Laboratories. The method already has been implemented by initial production facility projects and now is being used to produce thousands of ampules for use in the PS 115, PS 127, and PS 416 reserve power supplies.

Improved Drop Safety

Much R&D has been conducted at Harry Diamond Labs and at the laboratories of several contractors on copper ampules. The emphasis of the work was on performance and reliability. The copper ampule design with spin and setback gives improved drop safety over the glass ampule.

To assure that the procurement cost for PS 115 power supplies was minimal and handling safety was maximum, process engineering for semiautomatic, high speed manufacturing and testing was needed in making the production model of the copper ampule. An exploded view of the ampule is shown in Figure 1.

Cutter Assembly Machine Built

The objective of this project was to design and build an ampule assembly machine and a cutter assembly machine. Union Carbide was contracted to perform this work.

The cutter assembly machine (Figure 2) automatically die cuts the cutter plate and assembles the cutter blades to the plate. At the first stage of the machine, a Lourdes die press blanks the cutter plate from a continuous strip of copper and folds the blade tabs up. The next three operations place cutter blades. Each operation picks up one blade and places it on a specific pair of cutter plate tabs. The blades are supplied to the machine from vibratory bowls by way of vibratory inline tracks. Following blade placement, the last stage is another Lourdes die press which crimps the blade tabs, bends a preliminary fold, completes the final fold to a specific angle on the blade tabs and blanks the outside diameter. The cutter assembly machine automatically inspects the assemblies for missing or improperly positioned blades.

Ampule Assembly Machine

The ampule assembly machine (Figure 3) automatically assembles the components of the ampule by combining cartridge assembly, weight, and ampule can together with cutter assembly, diaphragm, weld ring, electrolyte, and bromide.

The ampule assembly machine system consists of two identical 24 station indexing dial assembly machines. The machines are controlled by a pair of common Allen Bradley programmable controllers. Nonliquid parts are supplied to the machine as required from feeder bowls. The ampule assembly machine is supplied with cartridge

NOTE: This manufacturing technology project that was conducted by Union Carbide thru the U.S. Army Harry Diamond Laboratories was funded by the U.S. Army Electronics Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The HDL Point of Contact for more information is Andrew Sabonis (202) 394-3114.

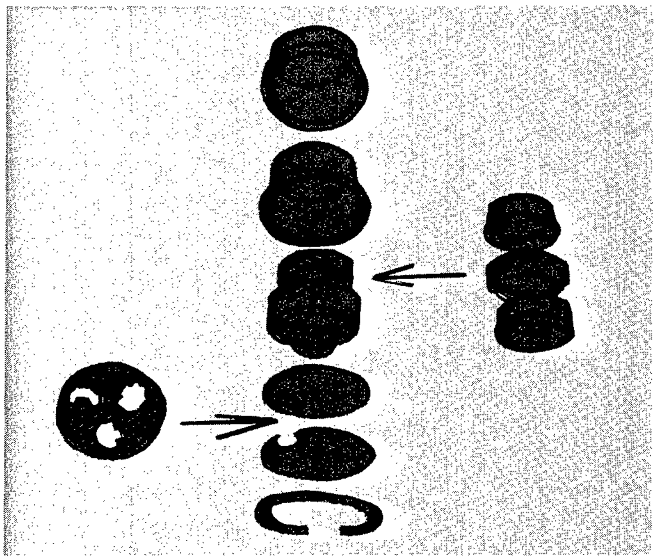


Figure 1

assembly and weights inserted into an ampule can via a parts conveyor. Pickup arms place the unit into a table nest in the proper sequential order. An injection of methylene bromide is put into the cartridge assembly, followed by an injection of fluoboric acid. A cutter assembly is placed into the can and a single diaphragm is placed upon the cutter assembly. A weld ring is placed upon the diaphragm and the ring and diaphragm are TIG welded to the can. Both the diaphragm and weld ring are supplied to the machine through cylindrical magazines. From the magazine the parts are picked and placed onto the balance of the assembly in the machine nest.

Inspection a Critical Step

All assembly operations performed are verified by probing (electromechanical gaging) at subsequent stations. The control logic also verifies proper operation at various steps, and shift register control cancels any further operations to any component failing verification. Incomplete assemblies are automatically rejected. Acceptable assemblies are 100 percent inspected before continuing their assembly operations.

Systems Manual Puts It All Together

An important part of this project was the preparation of the **Systems Manual for Operating and Repair Instructions.** This comprehensive work begins with a functional description of the fabrication machinery. It is pointed out that certain machines used in the manufacturing process are standard available types. However, the manual indicates where one machine can be easily substituted for another for a specific operation.

Next, instructions are given for dismantling and reinstallation of all the fabricating machinery and equipment required to produce the PS 115 reserve power supply. This is followed by a lengthy section on machine operation (operation of each individual machine used in the total process). Procedures covered include controls and indicators, start-up, manual and automatic operation, manual and emergency stopping, and restarting.

A section on preventative maintenance provides the information to keep the PS 115 machinery in good operational order. Instructions include all lubrication points, frequency of application, and type of lubricant to be used. Also included is an explanation of what adjustments may be required, their location, and how to perform them.

Figure 2

Added Sections Provide Bonus

The remaining two parts of this manual are devoted to troubleshooting (Figure 4) and recommended spare parts, including supplies. Drawings, photographs, flowcharts, and listings are used efficiently and effectively throughout to aid in understanding operations and following correct procedures.

This project provided a means and method to fabricate copper ampules for the PS 115 reserve power supply, which gives a significant improvement in drop reliability. In addition, an improved understanding of TIG welding principles for thin copper welding was gained.

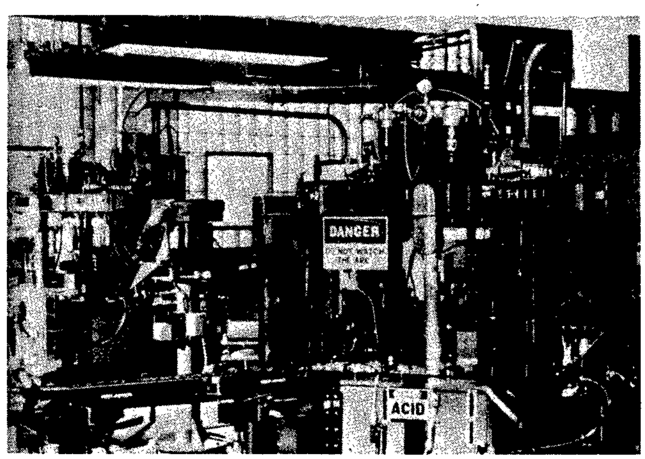
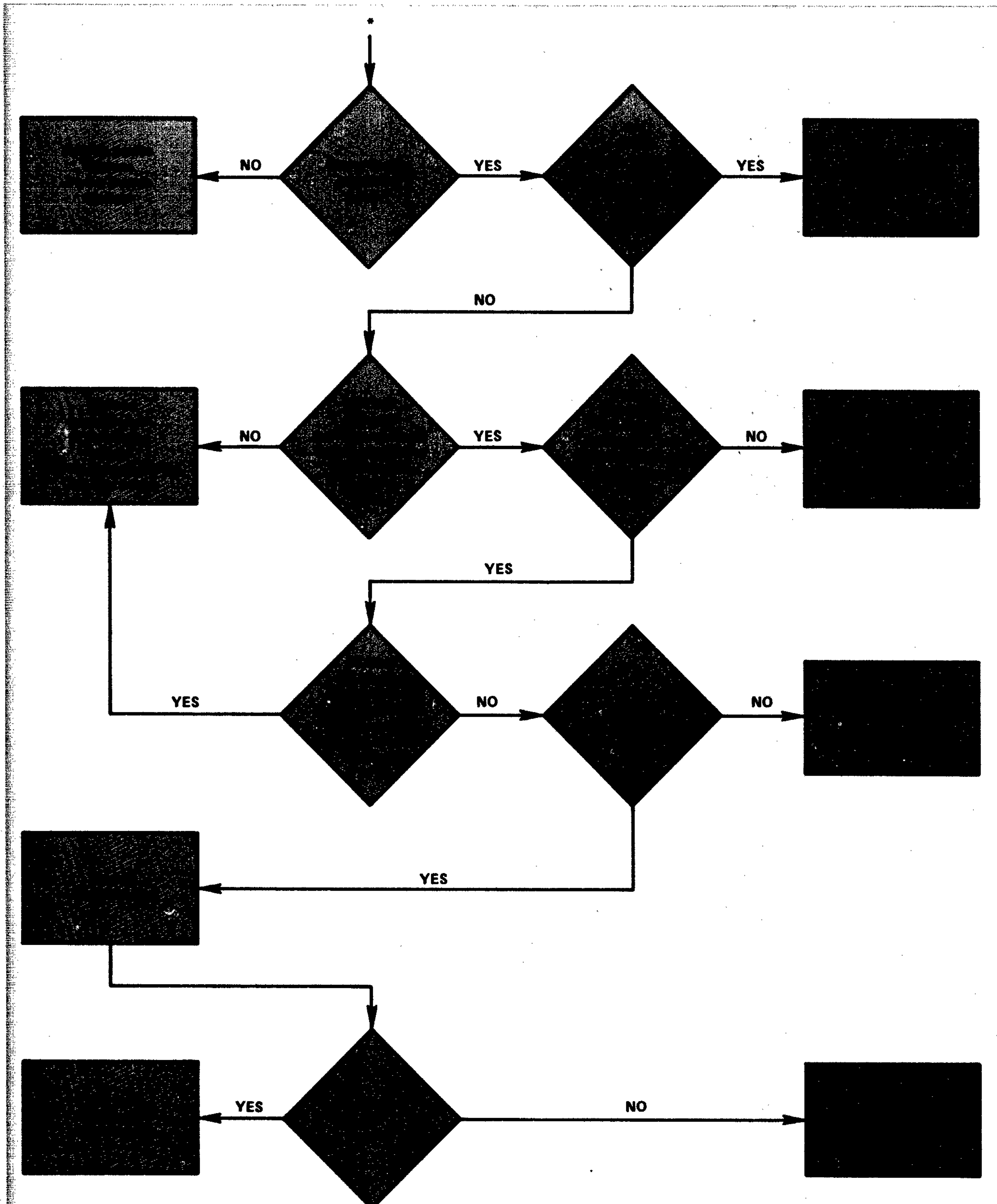


Figure 3



NOTE:
ON = Illuminated
OFF = Not illuminated

Figure 4

Pilot Plant Demonstrates Limited Success

Integrated Thin Film Transistor Display

By
Elliott Schlamm
U. S. Army Electronics Research
and Development Command

Continued development will make the production of usable integrated thin film transistor displays feasible, following pilot plant demonstration of a new process for their manufacture.

Aerojet ElectroSystems Company recently completed an MM&T project for the fabrication and application of thin film transistors (TFT) to electroluminescent (EL) displays for the U.S. Army Electronics Research and Development Command. The objective of setting up and demonstrating a pilot plant to manufacture TFT addressed EL displays was achieved. In accordance with program guidelines, the displays have an overall size of less than 4 inches by 8 inches an contain a minimum of 77 rows by 222 columns that are matrix addressable for alphanumeric and graphic data. Additionally, the display has memory and is low in power, lightweight, rugged, and sunlight readable.

Two Designs Completed

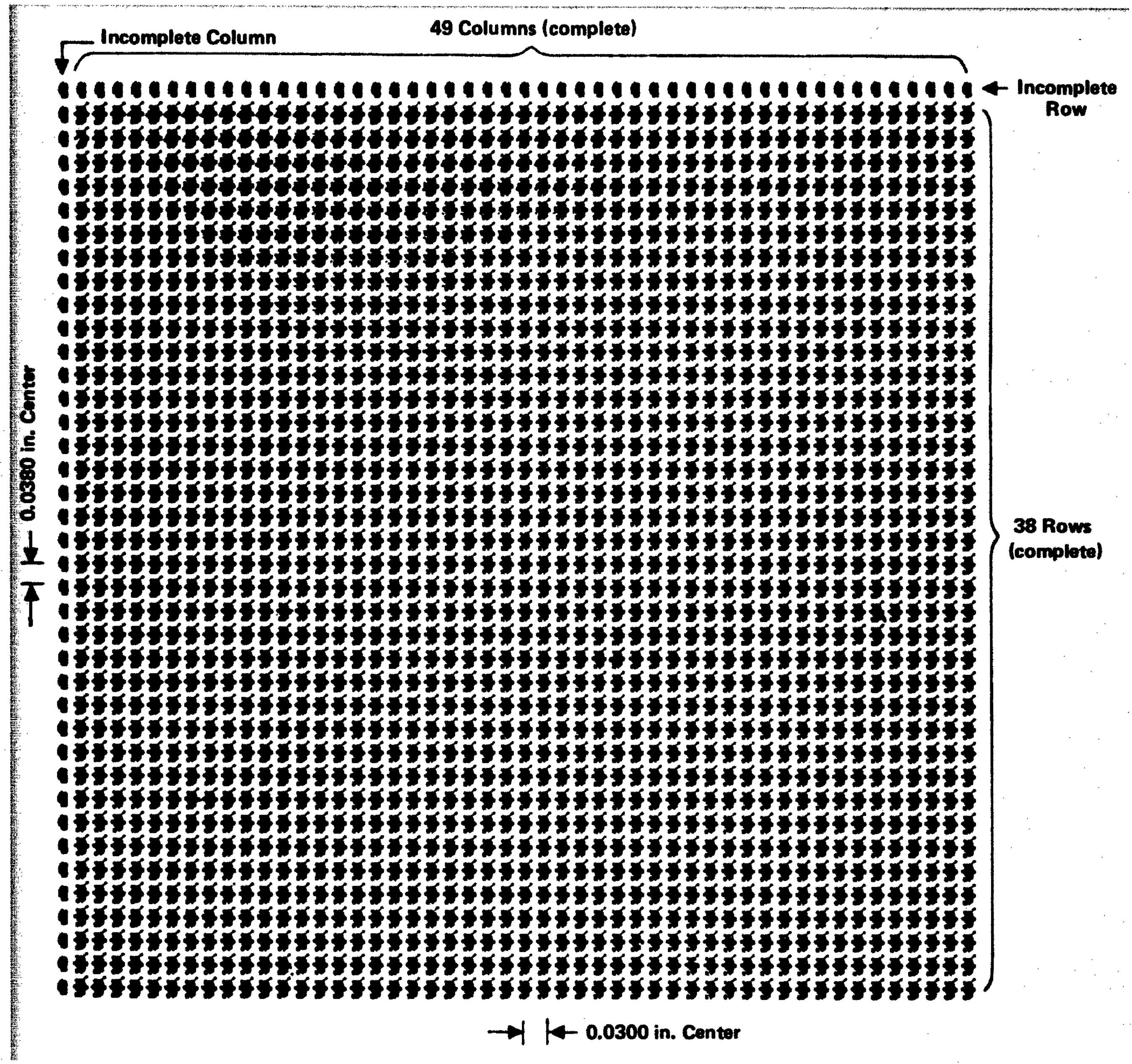
During this program at AESC two pixel designs were completed and studied in detail. The first—Active Matrix No. 1 (AM #1)—was fabricated as a pixel array of 38 rows by 49 columns on a 2.5 by 2.5 inch glass substrate (Figure 1). Once perfected, the matrix was expanded to full size (Figure 2) and made from four quadrants. The second—Active Matrix No. 3 (AM #3)—was fabricated as a pixel array of 80 rows by 224 columns on a single 2.5 by 5 inch glass substrate. The array was made for 80 rows by 224 columns to allow for extra test rows and columns on the perimeter. An actual photograph of an AM #3 EL display is shown in Figure 3; this design meets all the geometric requirements of the ultimate device on a single substrate.

A Unique Kind of Transistor

The thin film transistor is unique in that it can be made on a low cost substrate such as glass or polymer. As yet, however, there is no item in production using TFTs, because of (1) successes in metal oxide semiconductor (MOS) FETs; (2) technical problems in reproducibility; and (3) lack of a critical need.

A critical need currently does exist for direct view flat panel electronic displays. The successes in MOS have further accentuated the lack of low cost, low power, lightweight flat panel displays that are compatible with the new line of LSI microprocessors, memories, switching power supplies, etc. The technical problems with TFTs are not significant for the flat panel display application. The best approach is to keep the TFT circuits simple and the dimensions large.

NOTE: This manufacturing technology project that was conducted by Aerojet ElectroSystems thru the U.S. Army Electronics Technology & Devices Laboratory was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ERADCOM Point of Contact for more information is Marian L. Evains (201) 544-2881.



Incomplete Column
49 Columns (complete)
Incomplete Row
38 Rows (complete)
0.0380 in. Center
0.0300 in. Center

Figure 1

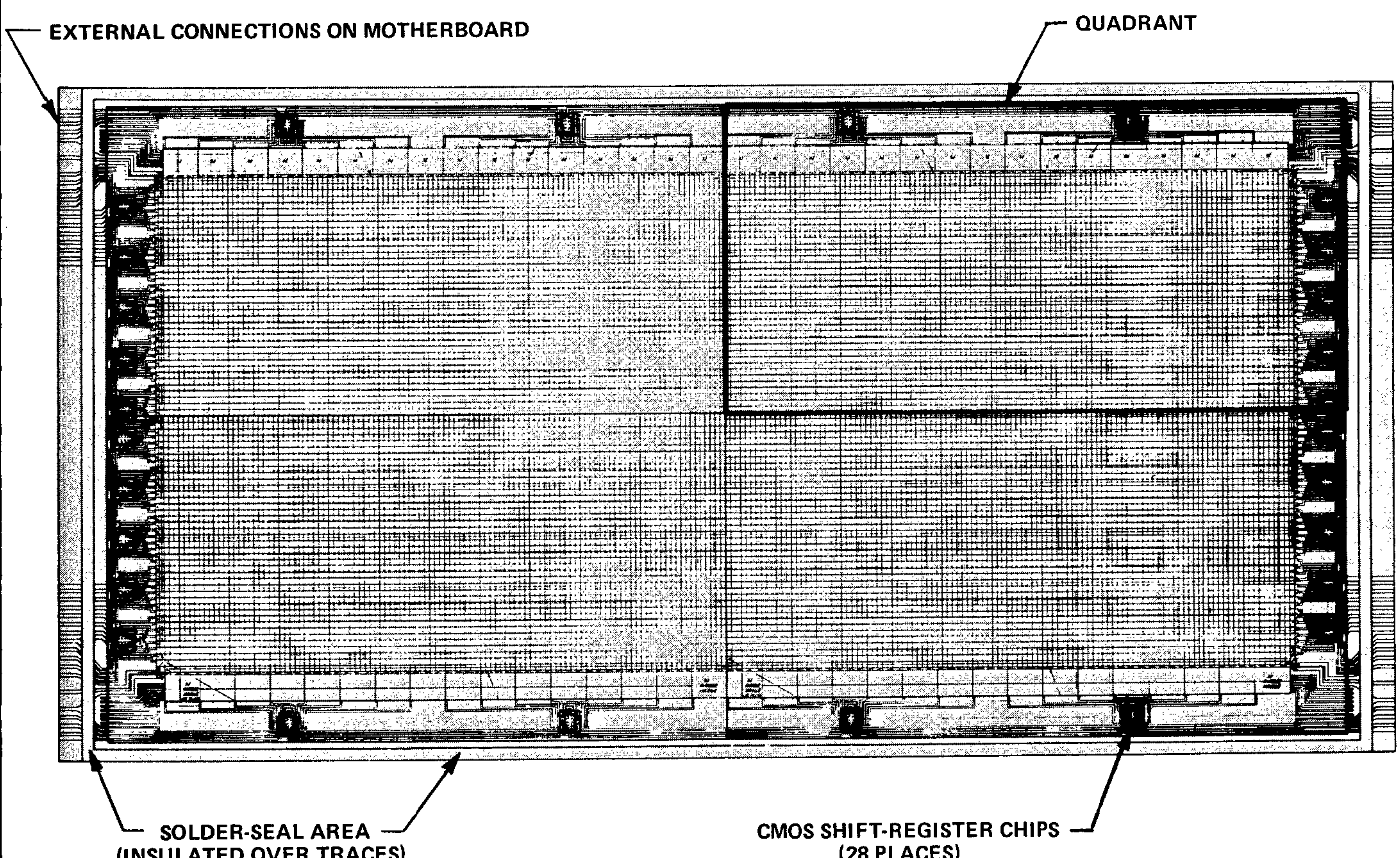


Figure 2

Flat panel displays have a unique requirement in that they must be matrix addressed. Matrix addressing inherently produces "sneak" circuits, which cause at least one third of the select voltage to be applied across all the nonaddressed pixels. Additionally, gas discharge and electroluminescent (EL) display technologies require a higher operating voltage than is readily available with MOS. Also, flat panel displays can benefit from memory storage at each pixel. The memory allows for a 100 percent duty cycle. Without memory, the duty cycle and brightness are inversely proportional to the number of display array rows. The TFT circuit at each pixel eliminates sneak circuits, provides the necessary voltage gain to stimulate the display media, and facilitates the incorporation of memory elements.

The contemplated display device is made up of four separate layers called stacks:

- The EL stack, which includes all those thin films needed for an EL display.
- The counter electrode stack, which includes the pixel electrode, a divider capacitor, and a ground plane.
- The TFT stack, which includes all pixel circuit elements.
- The addressing stack, which includes the row and column lines with intermediate dielectric.

The major TFT design considerations for a display of 77 x 222 lines or more are given in Table 1.

The TFT Stack

This transistor is more sophisticated than that originally developed, in that it uses dual gates (Figure 4). Dual gates provide sharper turnoff characteristics and a high Beta coefficient (geometric factor). The pixel circuit uses two TFTs and a capacitor for display memory, (Figure 5). The second transistor allows the display medium power to be separate from the addressing logic. Memory allows for a 100 percent duty cycle, as mentioned previously.

The entire TFT pixel circuit is fabricated on top of the pixel active area in AM #1 and next to it in AM #3. The pixel active area is defined by a metal electrode (or counter electrode). The TFT AM #1 pixel circuit is fabricated in one vacuum pumpdown, using five metal masks and ten additive depositions. Fabrication techniques used are:

- Deposition of materials through chemically etched Kovar metal masks
- Ball and race aligned tooling set for mask and substrate registration

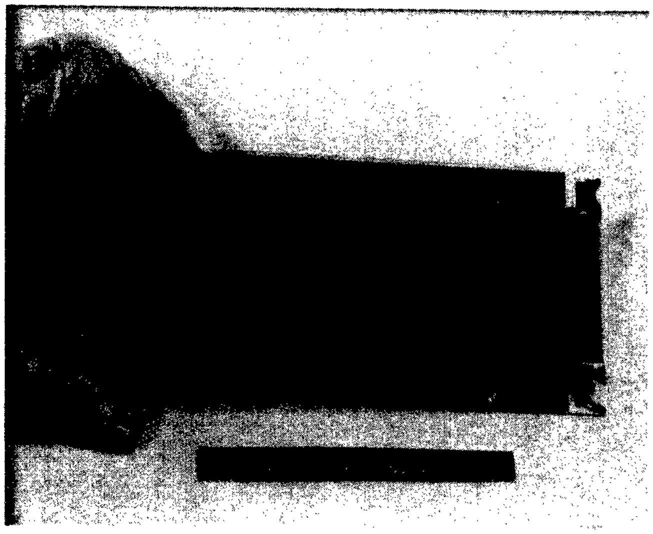


Figure 3

- Magnetic pulldown for mask clamping to substrate
- Tool and mask carousel for in-chamber interchange
- A three chimney vapor vacuum deposition chamber.

The TFT is a thin film polycrystalline semiconductor device. The most popular and successful devices use CdSe as the semiconductor, which is N type, enhancement mode. The Beta coefficient is under the designer's control. To improve the TFT, the following requirements can be satisfied with changes in the Beta coefficient and geometry changes:

- High current (higher gain)
- Higher transconductance (higher gain)
- Lower OFF current (dual gates)
- Higher voltage (thicker dielectric)
- Lower Miller effect (reduced gate to drain capacitance)—caused by gate and drain conductor overlap and channel capacitance
- Lower ON resistance (higher gain)

The TFT is a perfectly symmetrical electrical device if the source to gate geometry is identical to the drain to gate geometry. That is to say, the drain and source can be interchanged. When the TFT is turned off by making the gate slightly negative (-1 volt), the TFT has the electrical properties of a switch with leakage of less than 1 nA. The ON resistor is approximately 1 to 2 kilohms.

TFT Advantages	Application To EL	Application to LC and Other Nonemitters
Switch at Each Pixel	Not Needed, But Advantageous	Mandatory For Matrix Addressing
Memory	Advantage For 100% Duty Cycle	Mandatory For Matrix Addressing
High Voltage	Definite Advantage. H. V. Line Driver Only Option	Not Needed At All
Large Area	No Advantage	Advantage Over MOS
Low Cost	Must Be Lower Than H. V. Line Drivers	Must Be Lower Than Optional MOS Switch

Table 1

Counterelectrode Stack

The counterelectrode stack contains a capacitor used in series with the EL capacitance for voltage division. The EL requires approximately 300 volts peak to peak. It is desirable to address the display with CMOS, which is limited to approximately 15 volts peak to peak. The TFTs can be made to drive a load above 300 volts, but not with sufficient gain for only a 15 volt input signal. One solution for EL display drive is to add a capacitor and use a capacitor divider circuit. This capacitor is built at each pixel in the counterelectrode stack. It provides sufficient voltage drop that the pixel will not light. The second TFT shorts out the divider capacitor to turn on the pixel. When the divider capacitor is shorted out, the full voltage is applied across the EL thin film, which is electrically equivalent to a capacitor to a first approximation.

Electroluminescent (EL) Stack

The EL stack is built first on the substrate. The material is ZnS with Mn/Cu as the primary activator. The stack is optimized for steep brightness-to-applied-voltage performance. High brightness is not important, since the duty cycle is 100 percent. Brightness control is easily achieved with power frequency control. For frequencies below 1 kHz, the brightness is proportional to frequency.

A display with the EL performance achieved in this program is easily made sunlight readable. Since thin film ZnS is transparent, the use of a black light absorbing back layer or a reflecting back layer with front circular polarizer is applicable to achieve sunlight readability.

Addressing Stack

The addressing stack contains the row and column lines and accommodates the crossovers. The row and column lines are extended to the edge of the glass substrate for external drive at MOS level voltages.

TFT-EL Display

The complete display is shown schematically in Figure 6. The process profile for fabricating the display is outlined in Figure 7. Two basic approaches considered for connecting the TFTs to the EL are monolithic and sandwich (Figure 8). Only a moderate effort was applied to the sandwich configuration, since difficulties were encountered in electrically connecting the two halves of the sandwich.

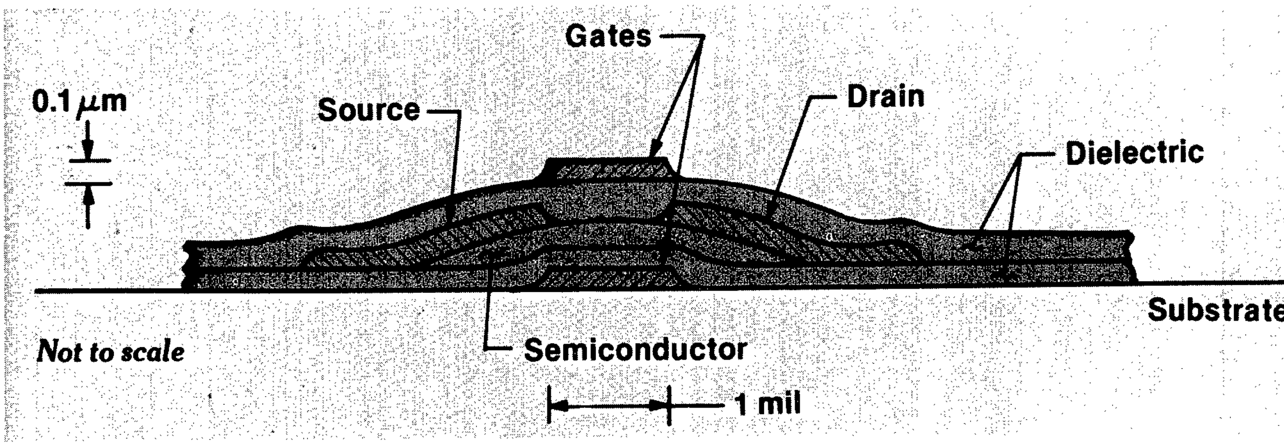


Figure 4

EL is the most efficient light emitting display, except for cathodoluminescent techniques. The EL panel has a high imaginary power component, which cannot be easily saved when it is supplied along with the display logic. In the approach here, the logic and display power are supplied from different sources. Therefore, a resonant circuit can be used to save the imaginary power component.

Active Matrix #1 Design

AM #1 had four major process problems:

(1) A hole had to be ion milled through the counterelectrode stack and back filled with metal to connect the TFT with the EL pixel area electrode. This required a resist photolithographic step, an ion milling step, a metal deposition step, and a resist removal step. However, the wet processing usually caused contamination of the substrate. Ion milling would make a hole at the counterelectrode contact layer, then thin film metal would be applied through the same resist to connect the TP with the counterelectrode.

(2) A thick insulating film, such as Riston, had to be used in the addressing stack to prevent capacitive coupling between row and column lines. The Riston was hard to apply repeatedly and etch without causing contamination to the thin film layers.

(3) The metal in contact mask design did not allow for any error in alignment that might arise due to thermal expansion, wear, or tooling variations. There was one critical alignment, and that was between the source and the gate of the high voltage transistor. If this alignment was not made to 0.1 mil, excessive capacitive coupling would occur which would erase the charge on the memory capacitor.

(4) The complete set of four stacks had too many thin film layers, which added to a morphology problem and reduced the yield probability.

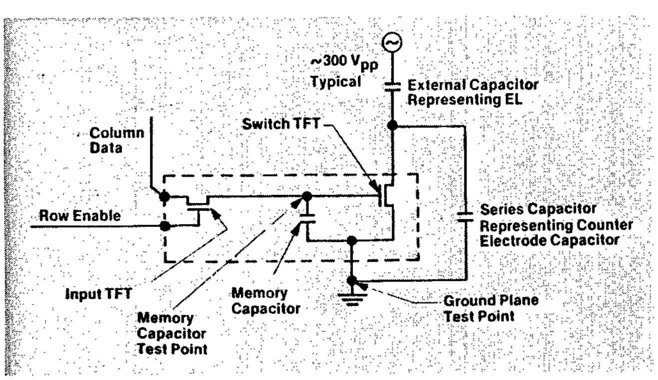


Figure 5

Active Matrix #3 Design

For the AM #3 design, all the problems of AM #1 discussed above (except 4) were eliminated in the redesign. First, the stacks were made all additive. By using overlapping additive mask deposition, the need to ion mill was eliminated. Second, all the layers were made additive including the addressing stack. The capacitive coupling was minimized through geometric design of overlapping areas. Third, an allowance of one mil of motion relative to all other masks was built into each mask during its design,

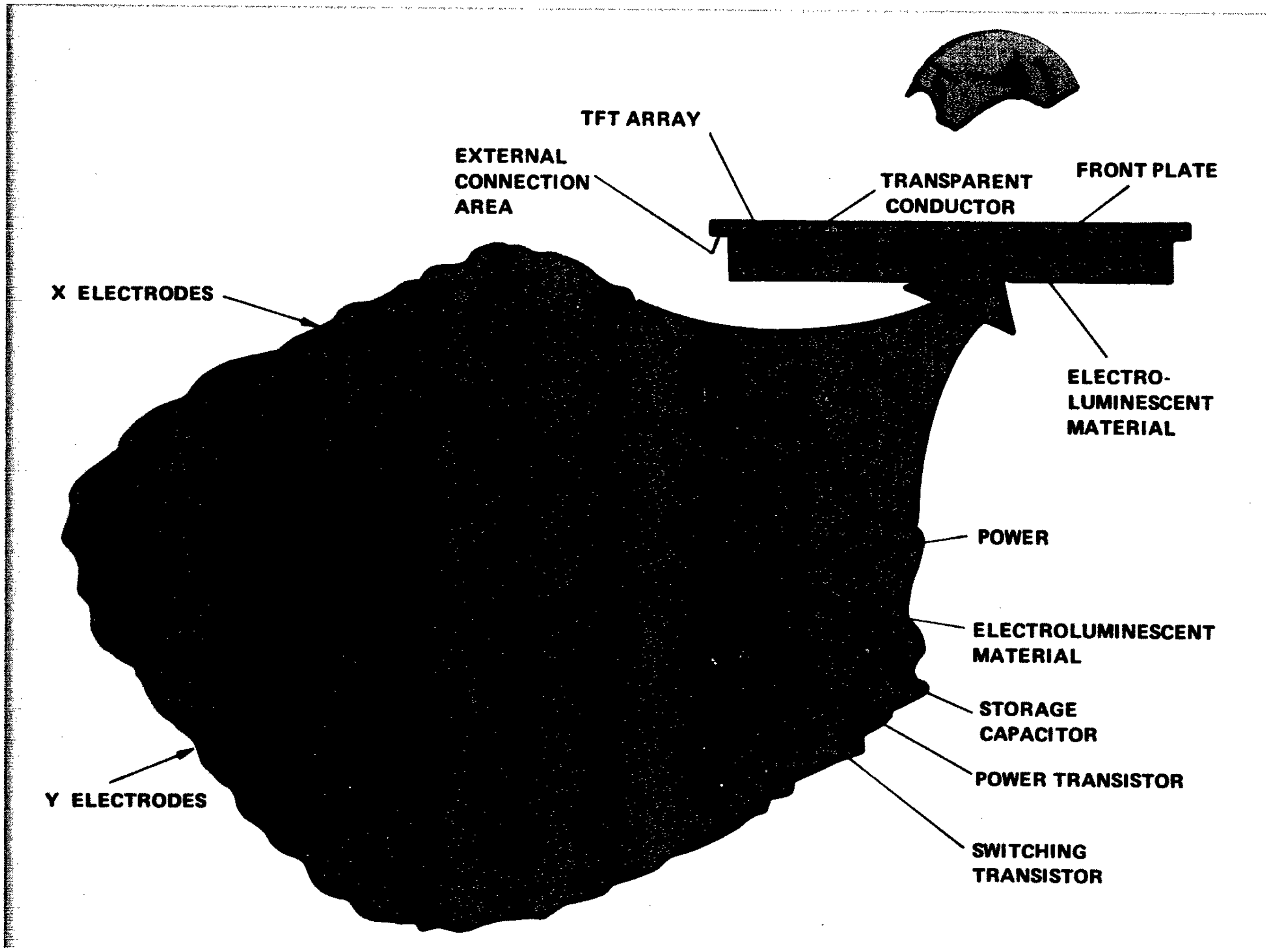


Figure 6

except alignment between gate mask and source drain mask. Fourth, the number of thin film layers was reduced, but not enough to completely eliminate the morphology problem.

The quadrant approach was abandoned. All the rows and columns needed were designed onto a single 2½ x 5 in. substrate, which greatly simplified the overall assembly. The resolution was increased to approximately 50 lines per inch; this was considered quite acceptable for the Army applications.

Problem Areas Complicate Success

Problems were encountered with error introduced by mask fabrication runout and heat induced mask alignment. Also, successful annealing could not be achieved at the required temperature.

The lack of complete success was indeed frustrating for several reasons. As previously mentioned, the total composite of thin films was made from four subsets—the EL stack, the counterelectrode stack, the TFT stack, and the addressing stack. Each of these stacks could be made, and all were tested and operated quite successfully. Further, corresponding pairs of stacks could be made and were operated successfully—however, all the stacks thus far were not made to operate successfully together except on a very limited basis. The major problem was that each film was made, its surface roughness would be replicated through the next surface. As the films accumulated, the roughness would be multiplied until the size of the anomalies exceeded the thickness of the succeeding thin film; at this point, the performance would become erratic. This was then compounded by the internal electric fields applied to the phosphors, semiconductors, and dielectrics—which were as high as 2MV/cm. Any pinholes at these field strengths would arc and destroy the entire film in the vicinity of the arc.

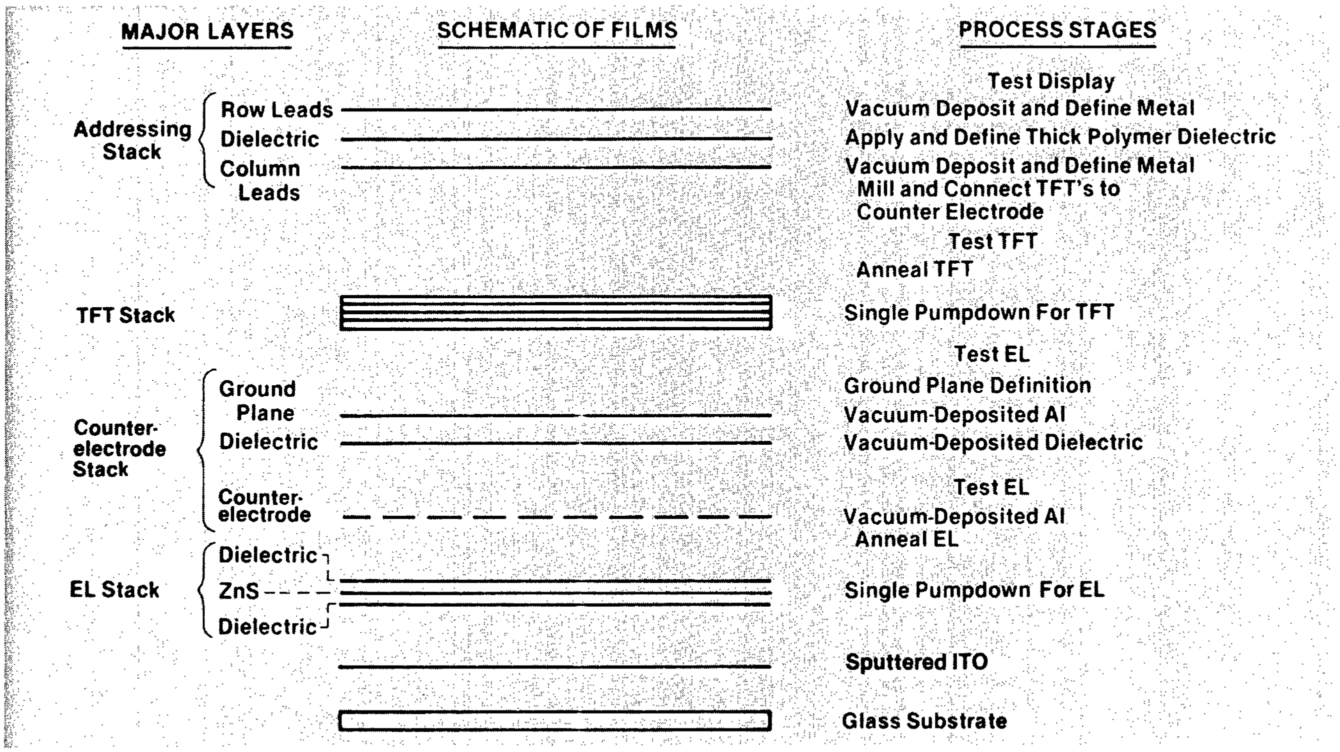


Figure 7

The unforeseen problems experienced on this program relating to surface morphology interaction render the present approach to making monolithic multiple thin film layers of this magnitude (approximately 44 layers) impractical without continued research and development.

It is presently felt that the overall process is not sufficiently mature for a pilot plant operation. Although a pilot plant was set up and demonstrated, the displays made by this plant were not fully satisfactory. Further development is expected to resolve the problems defined.

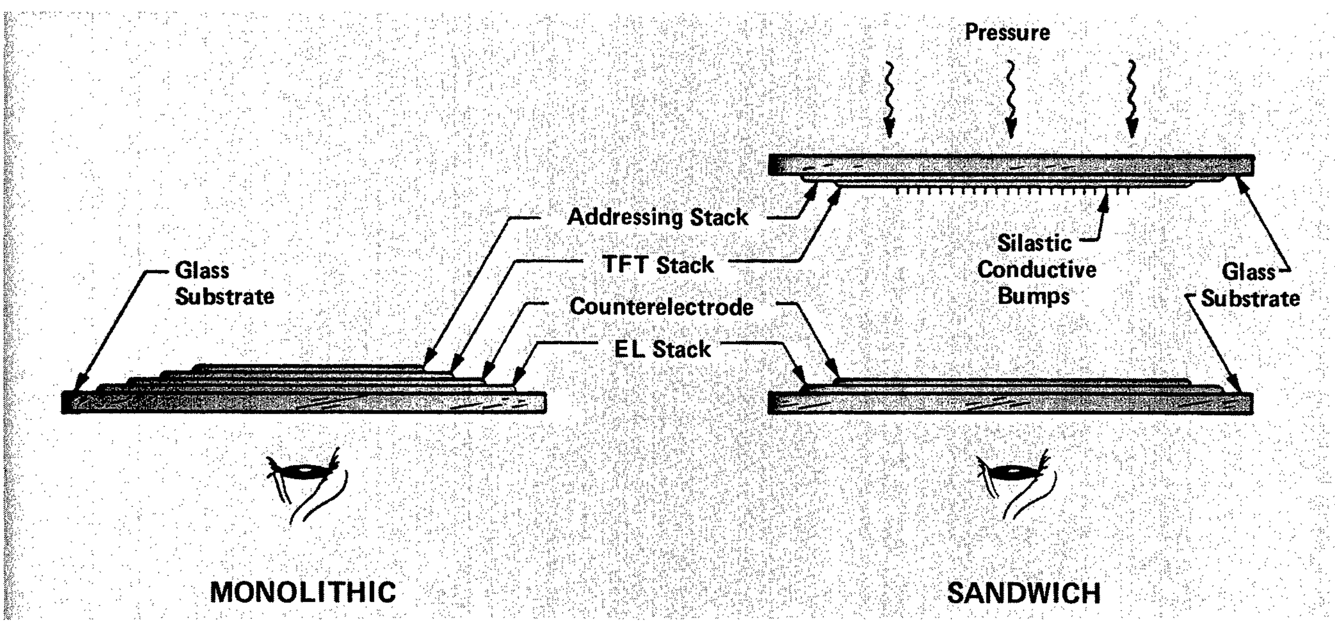
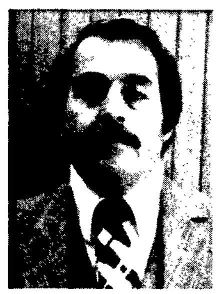


Figure 8

Technology Joined

Pultrusion Adaptation for Helicopter Component Manufacture

EVAN E. BLAKE is a Senior Engineering Specialist with Bell Helicopter Textron, Inc. in Fort Worth, Texas. After receiving a Bachelor of Science in Physical Science (1960) from California State Polytechnic University, he joined Shell Chemical Company's Adhesives Department. His over twenty years experience in thermoset and thermoplastic materials and processes ranges from development through management positions in manufacturing and sales. His present duties in Manufacturing R&D at Bell include investigating new methods of plastic processing.



By combining two processes—pultrusion and postforming—Bell Helicopter Textron now can produce a straight preformed part and then change the shape of the preform without changing its cross section. Developed in a program sponsored by the U.S. Army Aviation Research and Development Command, this new technique provides an alternative to conventional fabrication techniques where weight savings, economics, and corrosion resistance are significant.

For a production run of 1,000 parts, the raw material costs for postforming and aluminum are extremely close at $1.42 per foot and $1.49 per foot, respectively, as shown in Figure 1. This is based on a prepreg cost of $5.00 per pound. Hand layup materials would cost $5.55 per foot, as significant savings could not be accomplished by increased volume.

The weight savings are significant, with the composite tracks weighing 1.5 pounds each versus 2.2 pounds for aluminum. This weight savings totals 1.4 pounds per ship for 2 tracks. At an estimated value of $100 per pound, the ship savings value is $140.

The labor costs for the composite tracks cannot compete in fabrication time with the standards set for the aluminum track if the realization is 100 percent. However, a new part could conceivably have different economics if extensive machining or other operations were involved, or if weight savings was a primary factor.

Pultrusion—35 Years Old

The pultrusion process was developed approximately 35 years ago; this process produces straight parts with many possibilities of cross sectional design. It was derived from the metal fabrication industry's extrusion process, which was developed about 1900 for producing economic constant section metallic parts. Since fiber reinforced plastic resins cannot be pushed through the die by extruding, they are mechanically pulled out of the die, thus the term pultruding. A typical pultrusion operation is shown in Figure 2. Most pultrusions are either of fiberglass/polyester or fiberglass/epoxy and are cured in the die. The result is a cross section of almost any degree of complexity as determined by the die, but always straight due to the nature of the die. It has found limited applications in the

NOTE: This manufacturing technology project that was conducted by Bell Helicopter Textron thru the U.S. Army Materials and Mechanics Research Center was funded by the Aviation R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AMMRC Point of Contact for more information is Noel Tessier (617) 923-5172.

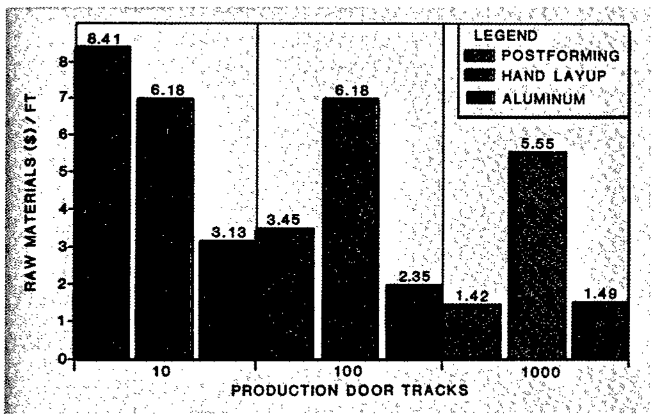


Figure 1

aerospace field, which has a small demand and volume for constant section straight parts.

Therefore, the ability to postform a straight pultruded shape into a curved configuration allows pultrusion to be considered for a wider range of applications. This postforming is accomplished before the resin material is cured. The pultrusion machine aligns and shapes the material to the desired form while advancing the state of cure. The pultruded part is not fully cured, but is left merely in an advanced stage sometimes called the B-stage. In this condition it can be formed while retaining the cross sectional shape and dimensions. This was the approach taken in this program.

The Program Plan

The program consisted of five tasks directed toward the development of a pultruded and postformed helicopter component. They were component and material selection, component design, specimen testing and evaluation, fabrication, and industry briefing. The actual component selected was the lower aft cargo door track for the U.S. Army UH-1 helicopter (Figure 3).

This part describes an arc 83 inches long with a 240 inch radius and a twist in the final 5 inches. A constant cross section lends itself to pultrusion and the gentle curve to postforming. The upper cargo door track carries the weight of the door; therefore, the only significant flight load on the lower track was found to be introduced by the lower door mounting slides. This force was calculated at 80 pounds in an outward direction perpendicular to the track face, which corresponds to a 0.345 psi air load on the door. This loading was regarded as well within the load limits of composite technology. The aluminum version of the track has been produced in the thousands so that substantial background information was available.

Material Selection

The material selection was as critical as the part selection. While the shape of the part would determine the potential for pultrusion, the matrix material would govern the ability to pultrude and to postform the preform. The matrix material along with the reinforcement is responsible for imparting the final strength requirements. Therefore, the material had to form a stable B-stage cross section in the preform to permit handling without disturbing the cross section and yet be malleable for insertion into the postforming tool.

The pultrusion process offered the first hurdle because the state of the art of the pultrusion industry did not lend itself to the production of B-stage materials. Virtually all materials are currently processed by wet pultrusion and cured at the die, providing a stable, finished product that need be only cut to length. As the vast majority of materials are fiberglass reinforced polyesters, vinylesters, or epoxies, the process produces a strong, economical, straight product suitable for industrial or consumer applications.

The initial tendency was to use a fiberglass reinforced epoxy due to Bell's familiarity with the processing and properties of this type of material. Consultation with Goldsworthy Engineering, Inc., who was the subcontractor for the pultrusion portion of this program, indi-

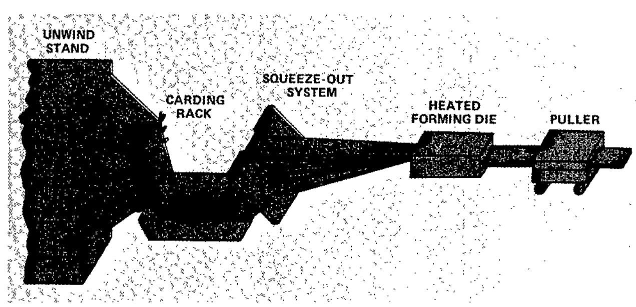


Figure 2

cated that they did not anticipate any significant problems in achieving the cross-sectional geometry of the preliminary door track designs with fiberglass/epoxy. They did feel that the inherent process restraints attached to epoxy pultrusion would limit the production rate to 2-3 inches/minute. An agreement was reached to evaluate alternative resins to determine whether a system was available to meet the requirements in a high production rate environment.

After a number of resins had been examined, ICI Americas' XPL 1056 vinylester was chosen as the candidate matrix material. The reasons for choosing this material are numerous. It has published properties approach-

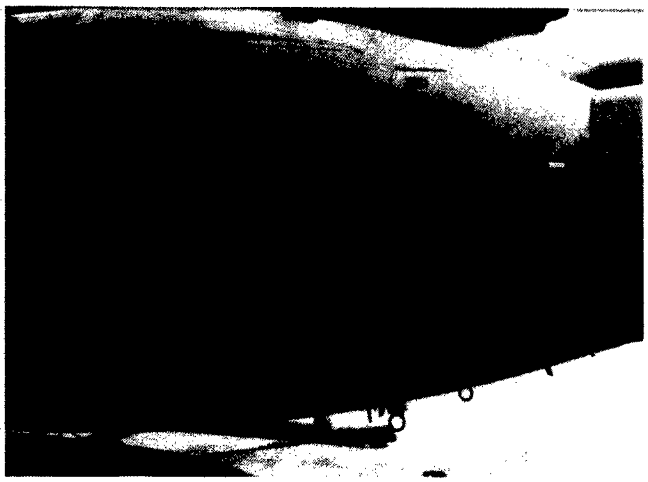


Figure 3

ing those of epoxies and can be pultruded at faster rates, 10-15 feet/minute. The resin cures extremely fast in 5-8 minutes at 285 F and has a thickening stage somewhat similar to an epoxy B-stage, which allows a preform to have a shelf life of one year at 75 F when packaged in aluminum foil. This thickening stage, referred to as maturation, occurs because of the reaction between a polyisocyanate and its polyurethane catalyst, forming a urethane suspended in the vinylester. The reaction takes place in 24 hours at 75 F or can be acclerated by the addition of heat. The vinylester does not enter into the reaction process and is therefore fully available for the final cure.

A sample of the XPL 1056 was obtained and test samples were prepared in the Bell Materials Laboratory. From all appearances, the XPL 1056 was the matrix material to design a composite door track around if it could be pultruded. This was to be confirmed or discounted in the pultrusion trials.

Door Track Design

A dimensional duplicate of the metal door track was regarded as feasible based on the data generated. The only exception was an increase in the wall thickness of 0.005 to 0.070 inches for additional strength. The fabric/roving/fabric vinylester composite appeared substantial enough to bear the 80 pound load. To test this concept, 0 degree flange test specimens were mounted in a test fixture and an aluminum slide was used to load the flanges with weights to simulate in-flight loading. The flanges broke at 434 pounds, indicating a safety factor of 5.5 to 1.

Recognizing that it would be difficult to pultrude two plies of 120 style E-glass fabric, the overwrap was changed to 1 ply of 7781 style E-glass fabric to provide transverse strength. The resulting composite of E-glass/vinylester, S-2 glass/vinylester, and E-glass/vinylester was judged to meet the mechanical requirements of the demonstration track through the range of -67 F to 165 F at 85 percent relative humidity. The loading requirement was set at 89 pounds to allow a 10 percent safety factor and the wear test at 200,000 cycles to reflect door opening and closing.

Pultrusion Tool Design and Fabrication

The design and fabrication of the pultrusion tooling was part of Goldsworthy's task. The pultrusion was to be attempted with XPL 1056 vinylester resin and fiberglass, therefore a heated die was designed and built according to Goldsworthy's drawing (Figure 4). The pultrusion processing parameters, however, were more complex than anticipated due to the problems encountered with the vinylester, liquid epoxy, and epoxy prepreg.

The XPL vinylester material was prepared and the fiberglass roving was then passed through the vinylester for entrance into the die. The next step was to pultrude the maturated preform. The die heat was reduced to 225 F and the run was set at 3 to 6 inches per minute, which corresponds to a heated dwell time of 5-10 minutes. Maturation was achieved, but some polymerization of the vinylester resin occurred. Varying the speed and temperature did not alleviate the problem. The maturation state was of a gel-like consistency which would not hold the roving and fabric together. In addition, the pulling loads exceeded 6,000 pounds, even with the addition of hydrate of alumina for viscosity control. The pot life of the vinylester was 1 to 1-1/2 hours, which was far too short for continuous pultrusion runs. All of these deficiencies in the vinylester system precluded the use of the system in this state. Because of the time constraints, the decision was made to use an epoxy system familiary to Bell personnel—U.S. Polymeric's E773.

The U.S. Polymeric E773 cures fully at 250 degrees F. Polymerization starts at 200-220 degrees F and proceeds to completion without passing through a B-stage. The product required for a preform would be a hot-melt, hard at 75 degrees F and soft and flowing at elevated temperatures. This could be accomplished by keeping the pultrusion temperatures of the E773 below 180 F allowing long working periods. For trial purposes, 130 pounds of 70 percent solids E773 solution was purchased.

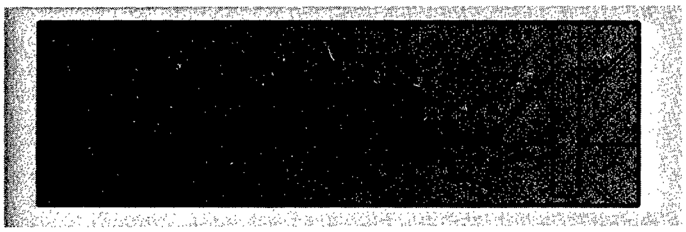


Figure 4

More Problems Encountered

The resultant product was far from satisfactory. The epoxy started sticking in the die and fabric fragments sheared off and magnified the problems. This precipitated frequent shutdowns for die cleanup. The matrix did not sufficiently wet out the fabric or roving, resulting in a fragile, nonuniform cross section which appeared stiff and low in resin content. The lack of impregnation was due to a combination of the high solids content of the bath and the heated die driving off residual solvent.

The next step was to attempt to pultrude E773 prepreg for evaluation. Two hundred pounds of E773 prepreg roving, 60 end count, was purchaed and a roving was pultruded through a 150 F die; it produced a nice looking, handleable preform without good transverse strength. An additional trial adding wetted fabric produced a preform with the fabric peeling off in handling and, due to lack of control in fabric application, poorly covered.

Changes Provide Breakthrough

Changes in the die configuration, fabric folding and the fiberglass fabric/resin form provided the breakthrough needed. Another four-inch die was machined and plated 0.010 inch undersize and a third four inch die was machined and plated 0.005 inch oversize. This provided a three die system, with the primary die undersized to form and debulk the prepreg rovings, the secondary die net size for fabric application, and an oversized tertiary die for cooling of thė preform. A new fabric folding shoe designed by Goldsworthy enabled the fabric to be wrapped around the prepreg roving form in two pieces instead of four, making it much easier to control. At the same time, the fabric/resin composition was changed to Hexcel's F185 adhesive prepreg, which is a 50 percent resin content 7781 weave E-glass material curing in 90 minutes at 265 F. This material also has been used at Bell and is compatible with E773.

The materials cooled sufficiently upon exiting the secondary die to stabilize without use of the tertiary die, and the preform was exactly as required. The dies were controlled at 150 F, yielding a feed rate that was increased from 3 to 10 inches per minute as the trial continued with loading at 4,000 pounds. The cross section was uniform and stable, while the fabric and rovings held together during handling but were malleable enough for slight changes at room temperature. The final door track pultrusion operation is shown in Figure 5.

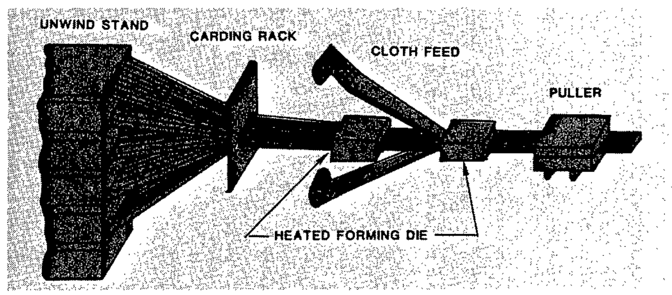


Figure 5

Test Specimens Pass Testing

Test specimens were taken from a section of a finished door track and tensile and flexural tests were performed according to Federal Standards. These specifications were used solely on a comparative basis. However, good consistency was shown in all tests, with the tensile values far exceeding those for the E-glass fabric prepreg but falling short of those for the S2-glass prepreg roving.

During static testing, the average failure was 237 pounds, which is 2-1/2 times the design load of 89 pounds. Also, during wear cycle testing, no discernible wear was observed after 200,000 cycles.

Future Work Recommended

Although this program proved the technical and economical viability of postforming pultruded shapes, the following areas of further study are recommended:

- Define the ultimate curvature to be obtained by postforming.
- Investigate potential applications to other helicopter components.
- Evaluate graphite/epoxy and Kevlar/epoxy to determine their processability.
- Consider creep forming as a method to further shape the part after postforming.
- Investigate methods of improving the handling characteristics of vinylesters due to their tremendous potential for cost reduction.

Voice Recognition Input to Graphics

Voice Controlled Computer Programming

By

Dr. Emory Zimmers
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The preparation of programs for computers and preparation of part programs and tapes for Numerical Control (NC) Machine Tools typically is done by manual input via keyboard. This traditional input methodology is susceptible to error and is time consuming. Prior to this effort, there were many different types of commercially available user specific voice recognition units which had made it possible to communicate with a variety of computers. This project was undertaken by Lehigh University for the U.S. Army Depot Systems Command (DESCOM) to incorporate voice controlled programming equipment into existing computer systems and to establish compatible software programs.

Two Turnkey Devices

This study was initiated based on the belief that the integration of voice recognition with a turnkey graphics system for the purpose of numerical control part programming may allow productivity improvements to be realized. The problems and the benefits associated with the interfacing of two turnkey devices (the voice recognition unit and the interactive graphics system) were addressed along with an analysis of the various benefits

NOTE: This manufacturing technology project that was conducted by Lehigh University thru the U.S. Army Tobyhanna Army Depot was funded by the Depot System Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The DESCOM Point of Contact for more information is Frank Estock (717) 894-7099.

and limitations of using voice recognition as input to interactive graphics. Although specific vocabularies were prepared, more importantly, a methodology for establishing new vocabularies was described and presented. In addition, several environmental factors were tested for their effect on the integration of these two devices: vocabulary size, background noise, and storage time. The effect they have on the efficiency of using the voice recognition unit for input is described.

Several Problems Addressed

When considering voice recognition for input to the specific turnkey graphics system used in this project, there are several problems to be addressed. The first of these problems is integrating the voice unit into the graphics network. This problem can be broken down into a physical linking problem and a logical linking problem. Physical refers to the actual mechanical connections, while logical refers to the links necessary to have the graphics unit recognize the voice unit as an input device.

Once the voice recognition unit has been successfully integrated into the graphics system another problem arises. This problem concerns the type of commands that are best suited for input into the graphics system via voice recognition. However, by the very nature of voice recognition, all words (or audio sounds) are not equally suited for input into any system. Because of this, there arises a fourth problem when trying to apply the voice to interactive graphics—that of selecting the words (or audio sound) to associate with the commands that are to be entered using voice recognition. An algorithm for selecting an audio sound for given commands can be found.

In summary, there are three major obstacles to overcome before voice input to a graphics system becomes a reality:

- Interfacing the hardware
- Selecting the commands
- Selecting the words to be associated with the selected commands.

Voice Recognition Units

In general, there are two specific types of voice recognition units that have been developed and tested, and both use basically the same scheme for automatic recognition (Figure 1). The difference is that the one type of recognition unit is "user general" and the other is"user specific". "User general" refers to the type of voice recognition unit that does not require preprogramming by the specific user that is to use it. This means that once a vocabulary is stored, anybody—irregardless of their own speech patterns—can access the vocabulary. This type of voice recognition analysis often is referred to as "phonetic analysis" because it analyzes the phonetics of speech rather than an audio signal.

"User specific" refers to the types of voice recognition units that must be trained by the specific person that is to access the vocabulary. The user's specific voice pattern is used while establishing the vocabulary set to be accessed later. This is usually done using a spectrum analyzer.

"User specific" recognition units are more compact, less complicated electronically, less expensive, and have a lower percentage of retrieval errors than the "user general" recognition units. The basic reason for this is the vast difference in the voice patterns of different people. With such a great variance in human speech patterns, it is very difficult for a machine to compensate and adjust to these differences. This compensation and adjustment is a task which the human ear and brain do very well; however, it is something that has not been duplicated efficiently either mechanically or electronically.

Emphasis on User Specific Recognition

The historic development of voice recognition units has been that of a transition from "user general" to "user specific". Bell Laboratories started to develop user general voice recognition units in the early 1960's, but after many tests and experiments they concluded that user

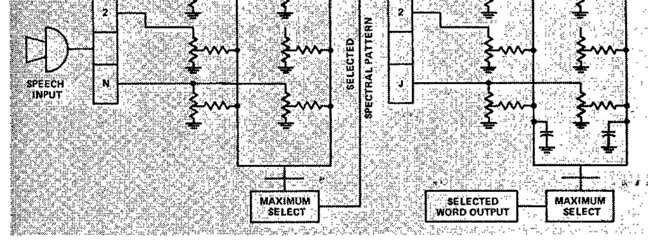


Figure 1

general recognition units were impractical because of the high percent of retrieval errors caused by different human voice patterns. Nevertheless, the groundwork was laid and the basic technological problems were solved in the area of voice recognition. With user general recognition units proving impractical, the emphasis in research and development shifted to the area of user specific units.

Today, there are many different types of user specific voice recognition units on the market which differ in respect to fitting algorithms, memory size, usefulness, and, of course, price. In choosing a specific unit, one must take into consideration both how and why the unit is to be used and, also, the environment in which it is to be used. Another consideration is the percent of retrieval of errors that can be allowed in a specific application.

Three of the basic distinctions in these user specific voice recognition units are (1) the allocation of memory for the stored vocabulary, (2) where the analysis is done, and (3) the ability to communicate with a host machine. Whether the vocabulary is stored in the recognition unit itself or in the host computer has a great impact on both the speed of recognition and the size of the vocabulary. Where the "best of fit" analysis is done (in the host computer or in the recognition unit) also affects the efficiency of the recovery system and the speed of recovery. To be useful, most voice recognition units must be able to communicate with other devices, usually computers. How they do this and the coding patterns used (ASCII, BCD, EBCD) varies between machines. All these things must be considered while choosing a voice recognition unit for a specific application.

Traditional Input Devices

One reason graphics systems lend themselves to voice recognition units is that they are designed in a molecular manner. By this is meant that a graphics system consists of several devices, each having an independent function, that fit together to make the system work. The four modules used for input and manipulation of geometric data are the keyboard, the menu, the function keyboard, and penstroke recognition.

Most Traditional Method

The **keyboard** is not only the most traditional way of entering and manipulating information in a computer but, in most graphics systems, it is also the most versatile. Any piece of geometry and any command recognizable to a graphics system typically can be entered using the keyboard alone. Because entering and manipulating geometry usually involves locating and defining coordinate points, the keyboard technique is not often used for entering or manipulating the geometry directly. This is because locating geometry and defining coordinates with any relative meaning is difficult in many graphics systems using coordinate points as a reference. Entering commands, however—particularly those that do not require selection of geometry—is a common use of the keyboard device. In general, the keyboard is reserved for either of two types of commands; the first of these is "backup." "Backup" in this sense refers to using the keyboard to enter a command after penstroke recognition, menu techniques, or if the function keyboard fails. Examples of these types of commands are listed in Table 1.

Command	Definition
GO	Repaint
GOSH	Update screen
KILL	Ignore last command
SE	Select everything
DD	Delete selected geometry
UU	Unselect
UNDR	Undraw selected geometry
GRID	Turn grid on or off

Table 1

The second general category of commands that the keyboard is generally used for are commands that are not used very often or with any regularity. These are the commands that are used every so often, but not often enough to define a penstroke or sacrifice a menu or function keyboard position. Examples of these types of commands are listed in Table 2.

Most System-Unique Method

Penstroke recognition is a method of entering and manipulating geometry that is rather unique to the chosen graphics system. What this basically entails is the user training the system to recognize a certain penstroke on the

Command	Definition
CDEF PTX	Change definition to Pollytex
USE PI 1	Use component PI on level 1
EDIT n	Edit level n
GRID n	Change grid size to n
SIN	Turn drawing information on or off
SH n	Show view n
CTRL	Return to control mode

Table 2

tablet as a command. The pen in the chosen turnkey graphics system has two states which it can be in while it is in use; these states are inking and tracing. Tracing refers to the state where the sensors in the tablet tract the pen while a mechanical switch is closed. The user closes this mechanical switch by pressing down slightly on the pen; he opens the switch by lifting up on the pen. By combining the two states of inking and tracing in various combinations, an infinite combination of penstrokes can be obtained. Thus, any and all commands theoretically can be entered using penstroke recognition.

There are two very important reasons, however, for limiting the number of commands that are entered by penstroke recognition. The first of these reasons is that, although there are an infinite number of possible penstrokes, it is not practical to use many that are very complicated. For a penstroke to be useful, it must be readily reproducible by the user. For this reason, a penstroke that requires a complex combination of inkings and/or tracings is useless. Also, a penstroke must be unique to ensure the integrity of this input feature. With too many penstrokes defined, the user runs a risk of having the graphics processor misinterpret one of the strokes.

The second practical and logical reason for limiting the number of commands to be recognized as penstrokes is the time involved in preparing a penstroke for recognition. It makes little sense to establish a penstroke for a command that will only be used on very rare occasions. This especially is the case if the penstroke is likely to be forgotten or becomes disassociated from the command by the time it is used.

Penstroke recognition when used correctly is perhaps the most powerful input device and control device in the chosen graphics systems input scheme. Of its many advantages over the other three input devices, there are three that stand out as being most important. The first of these advantages is sheer speed. Once a user becomes familiar with pen, he or she can draw a recognizable stroke very quickly and without much thought.

The second advantage of penstroke recognition is related to the user's focus of attention. While entering commands via the pen, the operator is looking and focusing his attention at the screen where the actual geometry is. The user does not have to look down to orient himself with the keyboard, menu, or function keyboard.

The one feature of penstroke recognition that makes it very powerful—and, in a sense, dominant—is that it is very closely related to cursor control. The reason they are so closely related is that the cursor provides the means of telling the graphics system where to insert geometry and text. Many of the penstrokes not only tell the computer to insert a piece of geometry, but they also provide a reference as to where to put it.

Most Space Limited Method

The use of a **function keyboard** to enter commands is also very useful in the chosen graphics system. A function keyboard is a system of buttons that the user can define to be interpreted as any command. Typically, the function keyboard is a set of from 64 to 128 buttons in an 8 by 8 or larger array. It is important to realize that, like penstroke recognition and the alphanumeric keyboard, the function keyboard theoretically can be used to execute any command.

In the opinion of some users, one of its dominant weaknesses is its limited space. Unlike penstroke recognition (of which there are essentially an unlimited number of unique strokes) and keyboard entry, the function keyboard has a limited capacity of commands directly associated with the number of buttons. For this reason, space on the function keyboard may be considered at a premium. Another weakness in using the function keyboard is that of orientation. Unlike the alphanumeric keyboard, in which a user develops a feel for orientation or penstroke recognition which does not require the user to look away from the screen, the function keyboard usually requires the user to make eye contact every time it is used.

One very big advantage to the function keyboard is that it can be used in conjunction with the pen. This means that

the pen can be used to specify coordinate points by controlling the cursor, while the function keyboard tells the computer what commands to execute. By this method both the position and the command can be entered into the graphics system.

Best for Infrequent Commands

The final traditional way of entering and manipulating geometry in a graphics system is by using the **menu**. The menu is accessed by pressing down on the digitized tablet (which is overlayed with a menu) with the pen. On the selected system there can be up to 432 (24 times 18) commands stored on the menu. The basic idea of the menu is very similar to that of the function keyboard, the main difference being that the command is chosen with the pen instead of the user's finger. Since the command is chosen with the pen, the pen cannot be used to control the cursor as easily in this method as it can while using the function keyboard. For this reason, menu commands are not usually the type that require high cursor control. Also, since there are so many memory locations, commands used very frequently are not usually used on the menu.

Since there are so many menu positions, the menu is very useful for commands that are used very seldom. The menu is also used for commands that require a lot of standardized arguments.

Voice Unit Hardware

The voice recognition unit that was first chosen for integration with the interactive graphics system was the Heuristics 7000 Voice Controller. After working with the Heuristics, which had only volatile memory, it was decided that a stand-along unit with disk capabilities would be better suited to the project. The voice recognition unit chosen was the Interstate Electronics Corporation Model VRT-101. This unit was commercially available.

This voice recognition unit has a maximum vocabulary of 100 words. The vocabulary and voice patterns may be saved on 5-1/4 in. 100k byte diskettes. The system carries one builtin disk drive and two external ones. This capability allows many people using a wide range of vocabularies to use the system interchangeably. Putting in vocabulary and the training of the vocabulary is made simple by use of the well documented VOICE program used for the VRT-101. The user is able to enter or adjust a vocabulary set easily and to retain or update single words as well as the entire vocabulary. The user may also test how well his voice patterns are picked up and can see the closeness of vocabulary words to each other.

The chosen voice controller listens continuously while it is enabled. It can, however, be disenabled very easily to allow for verbal communication between the user and someone else. The gain levels are all adjusted automatically, allowing it to adjust to the speaking habits of various users. The chosen unit is also self testing for major problems; in addition, it can be adjusted for different parity checks, duplex transmission, and baud rates.

Certain Commands Better

The first conclusion reached in this report concerned commands to be chosen for voice application. By analyzing the strengths and weaknesses of voice recognition it was deduced that certain types of commands are best suited for voice recognition. These are commands that are used very often but have low to moderate requirements in cursor control. As a result of this conclusion, there are more commands in the control set (such as "GO", "KILL", "GOSH", etc.) than in the addition and manipulation of geometry set (such as "ADD", "MOVE", "COPY", etc.) that are appropriate for voice input.

The next conclusion reached during this work concerned word selection. This was done by analyzing the basis of speech and the process of using the voice unit. Two specific recommendations were reached, the first being that the access word selected for a given command be logically associated with that command. This will aid the user in remembering the access words for the given application. An ideal case would occur when the user vocalized in the vocabulary set given. A second recommendation reached concerned word selection: elimination of minimally distant pairs, words, or phrases from the vocabulary set is desirable. This was decided after considering the basic units of speech called "phonemes". To ensure the uniqueness of a word selected for the vocabulary, the word should be examined in terms of these phonemes. This is the case because the electronics of the present day voice recognition units have a hard time in distinguishing between minimally distant pairs.

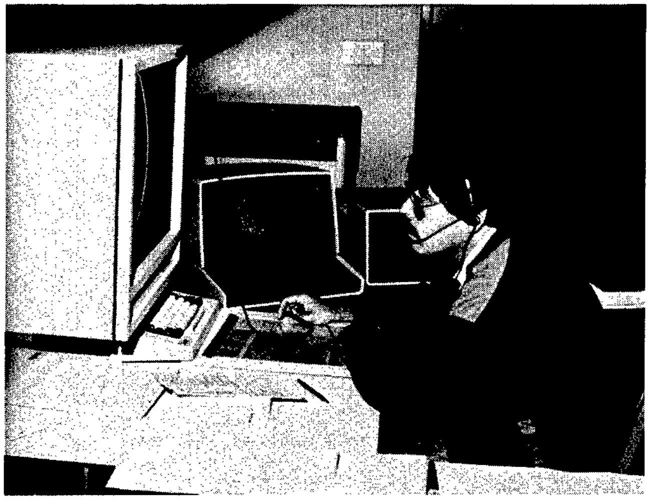


Figure 2

The final set of recommendations resulted from experiments of the three factors (background noise, vocabulary size, and storage time) effecting recognition accuracy. Results indicated that of the three factors tested, only the vocabulary size was found to have a significant effect on the retrieval accuracy of the voice recognition system. By the statistical analysis used, the two other factors were found to have no significant effect on the retrieval accuracy. As a result of this experiment, it was determined that excess words in the vocabulary set have a detrimental effect on the entire voice recognition network. It was concluded that the smaller the vocabulary size, the better the hit rate would be if everything else were equal. In a similar manner, it was concluded that reasonable background noise and storage time have no effect on the efficiency of the voice recognition unit.

Implementation to Save Money

The objective of this project was to accomplish an increased NC programming workload with the available manpower and existing programming equipment. The installed system is shown as Figure 2. As previously mentioned, the voice unit selected was an Interstate Electronics Corporation Model VRT-101 which was plug compatible with existing parts of the Applicon graphic system. External diskette drives were attached to store the operator's vocabulary and assist in processing data prior to transmission to the graphics host computer. This enabled the graphic system to view the voice unit as other peripheral devices—such as a keyboard or tablet, as illustrated in Figure 3.

The voice input was linked physically and logically with a turnkey graphics system. The integrated system was demonstrated to function effectively and with little or no degradation to the graphic controller for voice input to the NC software package. Recommendations were formulated for additional work on the association of words and commands. The results of this project can reasonably be extended to the 2-D drafting, 3-D drafting, and electrical design software packages of the Applicon graphics system.

The initial benefit from this project will be to reduce the cost of the preparation of NC machine tool tapes by approximately $45,000 per year at Tobyhanna Army Depot. Potential benefits may be derived from the extension of this capability to other applications for tool design and testing of electronic components.

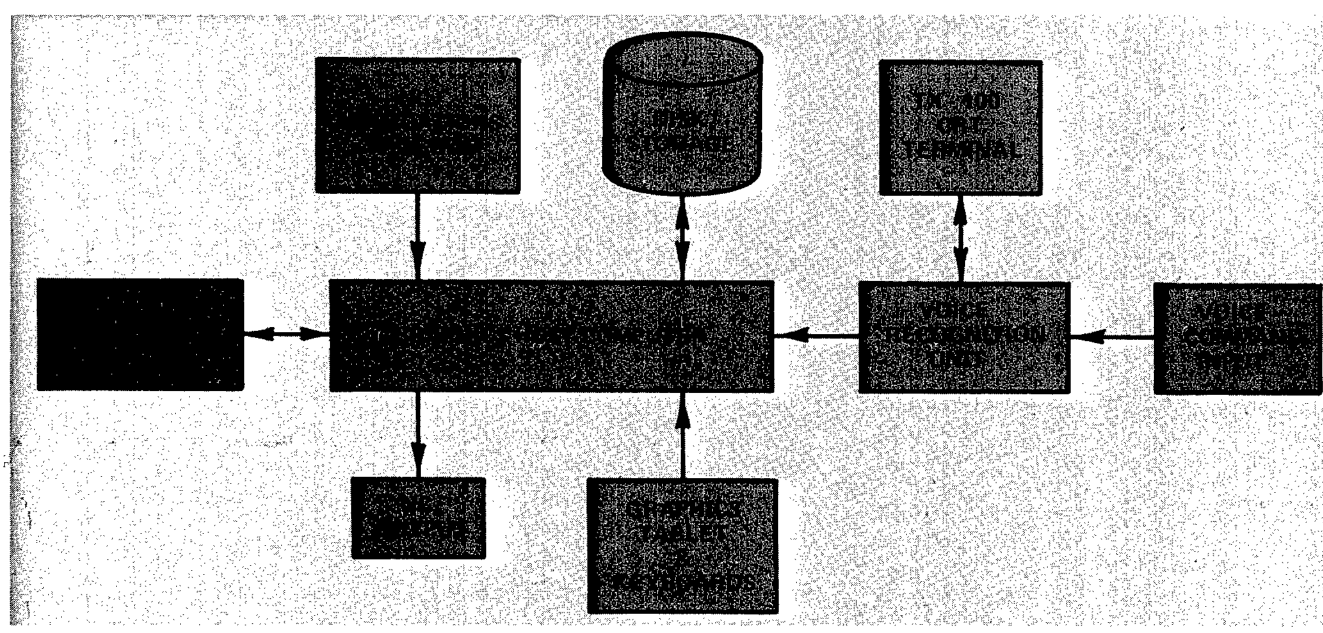


Figure 3

Ballistic Limits of Wrought Armor Met

Improved Large Armor Steel Castings

DONALD E. PHELPS is a Senior Project Engineer at the U.S. Army Tank Automotive Research and Development Command (TARADCOM). He holds a B.S. in Chemical Engineering from Tri State College, Angola, Indiana. Mr. Phelps has been associated with various activities related to armor and its fabrication since 1952. He currently is a Materials Engineer in the Armor Application Function of the Combat Systems Division, Tank Automotive Systems Laboratory, TARADCOM.

The Army currently uses large quantities of steel castings in the construction of heavy combat vehicles. The M60 tank consists primarily of cast armor turret and hull representing a major portion of the total vehicle weight. The M1 tank, while primarily consisting of rolled armor fabrication, requires a significant amount of steel castings and components. Limited prior work has shown that the cast product can be improved with current state-of-the-art methods.

The current work was performed by Rockwell International, Supply and Mass Transit Division (Atchison, Kansas), for the U.S. Army Tank-Automotive R&D Command (TACOM) and was planned to demonstrate both the feasibility and improved ballistic capability of improved armor castings through casting of large test plates and structures.

Cost Savings Possible

The purpose of this project was to investigate methods and procedures associated with the castings process that could be exploited to provide an improved armor casting. These include the use of additives to the metal, special chills, controlled solidification, improved feeding, location and size of gates and risers, and special heat treating procedures. The improved armor casting, with improved ballistic values, can contribute to cost savings by the elimination of welded rolled armor fabrication and by weight reduction, so the section thickness is only as thick as necessary to have the ballistic values needed.

Impact Results Improved

Three simulated section castings were produced using the information obtained from the cast plates. The ballistic limits of one simulated section casting did have about the same ballistic performance as a cast plate, when fired under the same conditions.

Improved feeding of both the 5 in. plates and the simulated section castings was obtained by using exothermic feed pads. The impact results were improved by using a hardness on the low side of the range and by using a specific heat treatment.

Vanadium Added to Help Refine Grain

The melting furnaces consist of four basic lined top charge arc furnaces. The furnace shell diameters are 9, 11, 11, and 12½ ft, respectively. These furnaces produce heats varying in size from 8,000 lb to more than 50,000 lb.

NOTE: This manufacturing technology project that was conducted by Rockwell International thru their Supply and Mass Transit Division was funded by the U.S. Army Tank-Automotive R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The TACOM Point of Contact for more information is Don Phelps (314) 574-5444.

The metal for this project was melted in the 11 ft or the 12½ ft furnaces. The furnace practice used is a single slag type where sulphur is lowered in the meltdown before the oxidation. The ladles are bottom pour and lined with a clay type brick.

Heats for this project were deoxidized with different amounts of calcium alloys: hypercal, graphidox, and calsibar. Vanadium was added to help refine the grain. The calcium aluminum deoxidation is to produce a Type I sulphide inclusion to improve the impact values. Normal aluminum deoxidation produces Type III inclusions with some Type II.

All pieces for this project were cooled in the mold from their casting temperatures to below 600 F before shakeout. After the shakeout, the pieces were blasted with steel shot to remove the sand. A preheat of 300-600 F was used for the gate and riser cutoff. All plates—48 x 60 x 5 in.—were stress relieved and machined on both faces before the heat treat. The simulated section casting and test bars—12 x 12 x 5 in—were not machined. All pieces from a heat were run on the same heat treat furnace load. The water quenching was performed in agitated water and the pieces were cooled to 200 F or lower before removal from the agitated water.

The heat treat furnaces are open fired furnaces producing an oxidizing atmosphere. This decarburizes the surface layer on the plates and simulated section castings to a depth of approximately 1/8 in.

Rigging Changed for Ballistic Plates

The 48 x 60 x 5 in. plates that were used for this project were poured in the upright position. A zircon sand chill was used on one side of the casting and an exothermic pad on the other side to provide feeding. The large riser on the top—lined with an insulation board—provided the metal to feed the plate. Gamma ray examination of the first plates showed a soundness level of Class 1 and some Class 2 for shrinkage and inclusions under MIL-R-11469 Specification.

The exothermic padding was therefore changed to sections of padding on the next two plates (Figure 1). The gamma ray soundness level of these plates was Class 1 and some Class 2 for shrinkage and inclusions. The two section exothermic padding was continued on the rest of the plates used for this project.

Two other changes in the rigging were tried and did not perform as expected. Two plates used a steel chill 2½ in. thick to replace the zircon sand. Both plates had excessive hot tearing and were scrapped due to these hot tears. This did not appear to be a practical way to cast the plates and simulated section castings. Two other plates were cast in the laydown position as shown in Figure 2. These two plates had a larger riser over the center of the plate. The removal of this large riser caused cold cracks in the plates that extended into the plates up to 1½ in. These plates were scrapped due to the cracks. If more plates

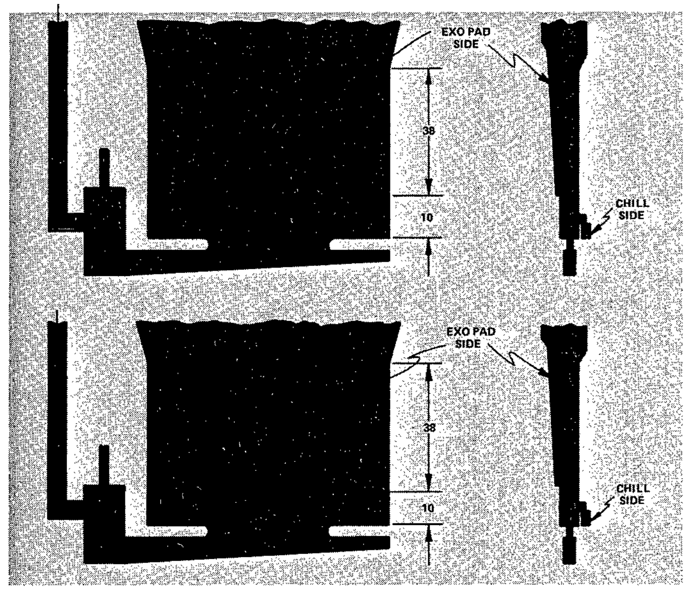


Figure 1

were made with this large riser, the riser removal would not be expected to be a problem.

Chemistry, Heat Treat, and Hardness

Two general chemistries were used to produce the plates and simulated castings. The one chemistry, which is close to the declared chemistry of the Atchison Plant is used for 3 to 8 in. thick cast armor and is as follows: C (.20/.30), Mn (.90/1.40), Si (.25/.70), Cr (.80/1.30), Ni (1.00/1.70), Mo (.60/.80), Al (.030/.065), Ti (0.15/added), and V (.12/added).

The other chemistry used to produce some plates and a simulated section casting consisted of: C (.20/.30), Mn (.50/.75), Si (.50/max), Cr (1.35/1.85), Ni (3.25/4.25), Mo (.30/.50), Al (.070/max), Ti (.015/added), and V (.12/added).

The hardness level on the first two heats of plates was produced on the high end of the wrought armor specification, MIL-A-12560D (MR). The specification hardness range is 241-277 BHN. It was later found that the ballistic limits and impact values improved as the hardness values were lowered to the low side of this range.

The heat treat on the first two heats of plates was only a quench and temper. It was found that this heat treatment did not give high impact values. Starting with the third heat of plates, the following heat treat was used for both chemistries.

- 1750 F — Air Cool
- 1650 F — Air Cool
- 1600 F — Water Quench
  + Temper (Water Quench)

This heat treatment was found to give the maximum impact values at -40 F.

Three test bars—12 x 12 x 5 in.—were poured from three of the 1.5 percent nickel grade heats. Each test bar was given a part of the total heat treat given the plates and/or simulated section castings. The impact values were improved when the bars were given the full heat treatment. No work was done to determine the minimum heat treat time necessary to give the maximum impact values.

Three test bars—12 x 12 x 5 in.—were also poured on two of the three heats of 4.0 percent nickel grade heats. It was shown that the full heat treatment of the 4.0 percent nickel grade does improve the impact values at -40 F.

One heat was air cooled from a tempering temperature of 1275 F and retempered at 1180 F with water quenching after this retemper. This heat treatment lowered the hardness to 248 BHN and showed a slight improvement in 0 degrees obliquity ballistic limits.

Lower Hardness Yields Improved Ballistics

The gamma ray of the 48 x 60 x 5 in. plates and simulated section castings showed a soundness level of Class 1 and some Class 2 for shrinkage and inclusions. The ballistic limit of plates was improved for these test conditions when the hardness was on the low side of the wrought specification; this range is 241-277 BHN. Cast plates with hardness of 241 and 248 BHN showed higher ballistic limits and impact values at -40 F than similar plates with higher hardness (Figure 3).

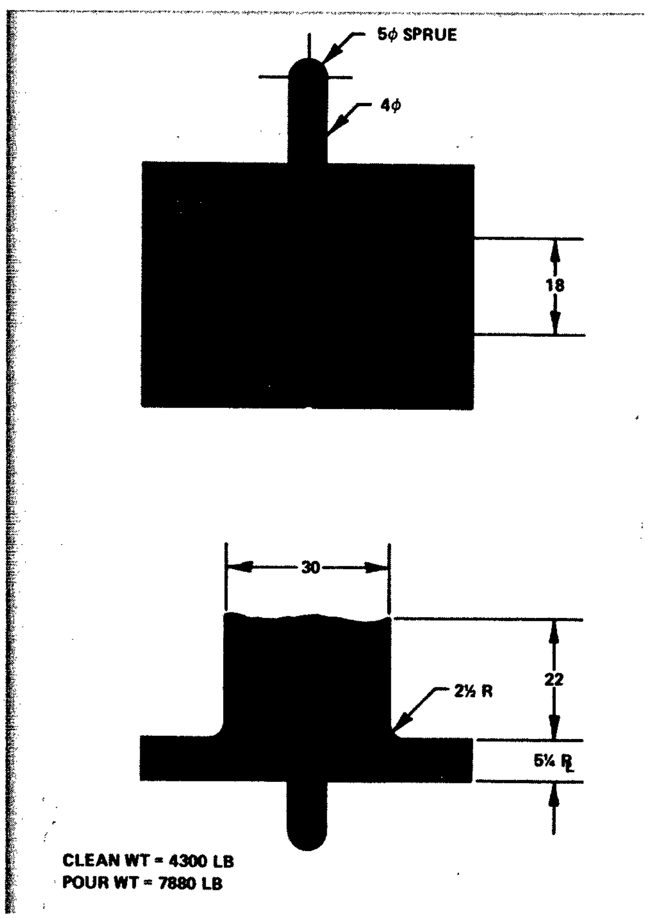


Figure 2

Two chemistries were used on the 48 x 60 x 5 in. plates. One chemistry contained approximately 1.5 percent nickel and the other 4.0 percent. Both chemistries produced about the same ballistic limits. However, the 4.0 percent nickel grade would not soften to 248 BHN when tempering was followed by water quenching. Extensive testing of the test bar material from this grade resulted in finding the lower critical temperature to be between 1200-1225 F. One heat was heat treated using this data, which lowered the hardness to 248 BHN. The heat treat is as follows:

- 1750 F — Air Cool
- 1650 F — Air Cool
- 1600 F — Water Quench
- 1275 F — Temper Air Cool
- 1150 F — Temper Water Quench

The 1.5 percent nickel grade was given the following heat treat that gave the improved impact values at -40 and the best ballistic limits:

- 1750 F — Air Cool
- 1650 F — Air Cool
- 1600 F — Water Quench
- 1150-1300 F — Temper Water Quench

Steel armor castings produced by optimized procedure demonstrated excellent metal soundness and significant improvement in the areas of charpy impact values and ballistic performance.

Recommended Production Specifications

A review of the results of this project show that impact values can be higher than that required by Specification MIL-A-11356E (MR). The following table shows the BHN hardness and impact values expected under MIL-A-11356E (MR) and the impact values to be expected when producing the Improved Cast Armor.

BHN	ft/lb at -40 F	Improved Cast Armor ft/lb at -40 F
255	38.0	44.0
242	40.0	46.0
241	42.0	48.0
235	43.0	49.0
228	45.0	51.0

The proposed increases in the impact values at -40 F for the Improved Cast Armor represents an increase of approximately 14 percent over the MIL-A-11356 (MR) specification.

It should also be noted that the proposed chemistry for the Improved Cast Armor has the molybendum lowered by .05 percent and an addition of .12 percent vanadium for some grain refinement. The phosphorus and the sulfur is expected to be below .015, and the combined phosphorus and sulphur should not exceed .035 percent.

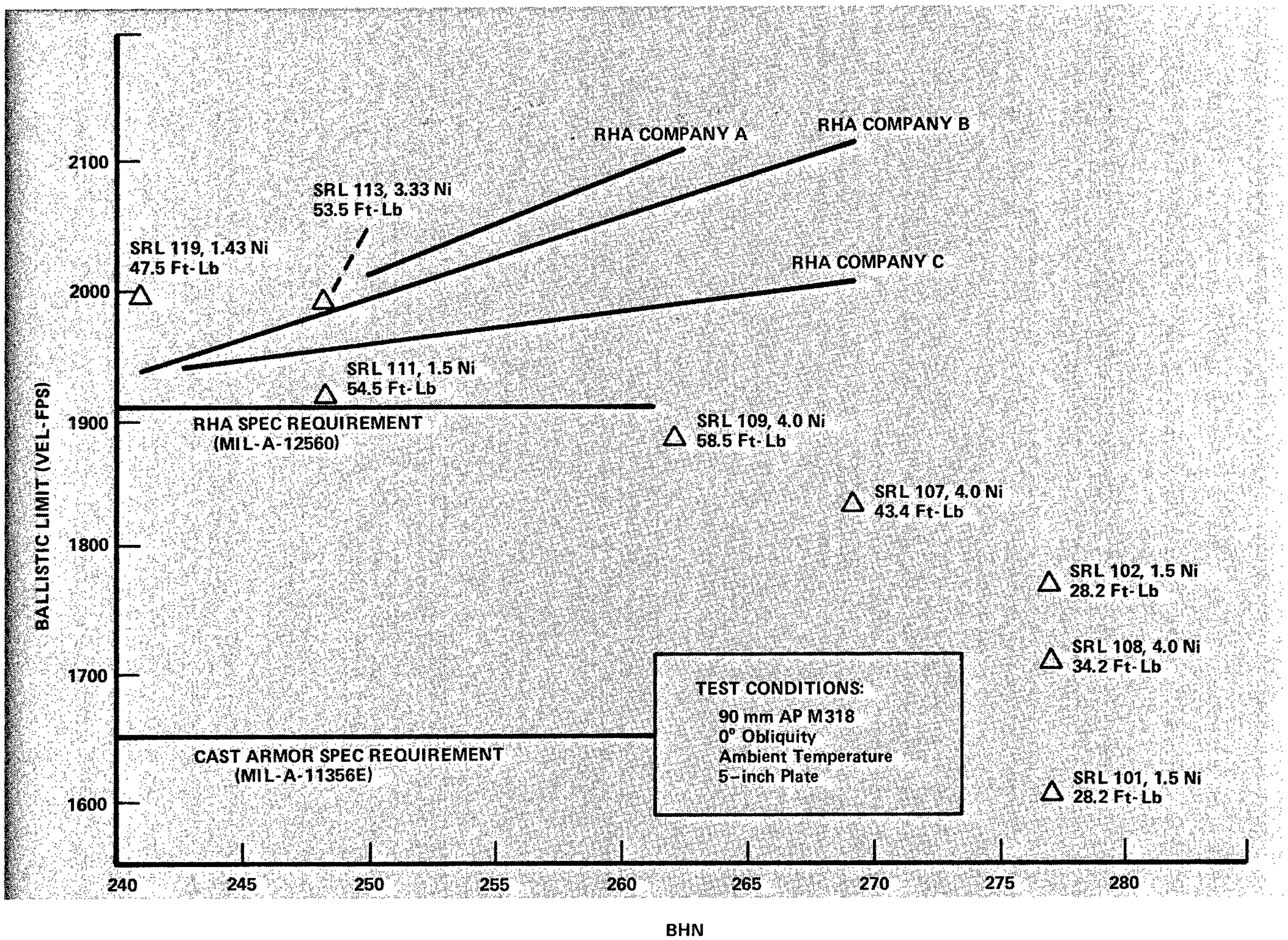


Figure 3

Further Work Recommended

Recommendations for future investigation and testing of improved large armor steel castings should include:

- Investigation of the feeding of castings by using impact data values obtained from different areas of the casting (gamma ray may not show the difference that is necessary for the improved ballistic limits; this impact data may be necessary on sample castings to establish the necessary rigging)
- Investigation of the feeding of castings by using insulation board in place of exothermic padding
- Investigation of ladle refining for the production of lower sulphur and lower inclusion contents, and also investigation of the modification of inclusions through the use of rare earth additions or calcium additions (this should increase on ductility and impact values at higher hardness levels)
- Production of a series of castings from one pattern using the optimum feeding, chemistry, and heat treatment (the castings would be used for testing or for use in the final product; this would check their usability for production and further validate the improved casting performance.

Cost Savings Potential

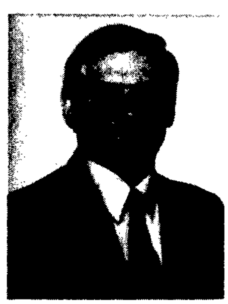
When cost estimates were made on the simulated section casting, it was found to cost 8 percent more when made to the proposed Improved Cast Armor instead of the normal MIL-A-11356E (MR) Specification. Each casting design will have its own production cost that is determined from a final working drawing. The increase in cost does not consider a cost saving of weld repair when using the optimum feeding of the casting. Production experience may show a savings of weld repair cost of approximately 4 percent. Also, a major benefit of using a casting with higher cost is improved ballistic performance as compared to castings currently produced. And, improved casting design can lower weight while providing approximately equal ballistic performance.

Potential Savings to Exceed $10 Million Annually

Delidding and Resealing Hybrid Microelectronic Packages

Rework is a vital part of manufacturing hybrid microelectronic packages. As military hybrids grow in size and complexity, the need for effective rework increases. Further, once a package has been sealed, almost all of the necessary labor and materials have been invested. If the hybrid fails at this point, scrapping is an expensive and undesirable choice. Removing the lid and remounting the substrate in a new package is possible, but this requires many extra handling steps and several thermal excursions which degrade the reliability of the hybrid.

Delidding and resealing, on the other hand, offers the capability to repair a circuit with minimum expense and degradation. Simply stated, delidding and resealing involves removing the lid from a sealed hybrid package, repairing the circuit, and hermetically resealing a new lid onto the original package. In addition to reducing the time required to complete a rework, delidding and resealing reduces the associated labor and materials costs and does not require additional thermal excursions.



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NOTE: This manufacturing technology project that was conducted by Westinghouse Electric Corporation thru the U.S. Army Missile Command was funded by the Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Paul Wanko (205) 876-7097.

Available Techniques Unsuitable

A number of manufacturers had at least a rudimentary technique for delidding and resealing hybrids. However, few, if any, were really suited to volume production use. The objective of the effort by the Defense and Electronics Systems Center of Westinghouse Electric for the U.S. Army Missile Command was to develop the equipment and processes necessary for effectively delidding and resealing hybrid microelectronic packages. The techniques developed were to apply to the most commonly used military hybrid packages and be easily implemented throughout the industry.

Objective Met by Four Goals

The objective was met by achieving four goals: the technique had to be reliable, fast, safe, and production oriented. (1) To be reliable, the technique had to ensure predictable, repeatable results. The lid must be removed cleanly; the enclosed circuit must not be damaged or contaminated such as exposure to heat, particles, static electricity, excessive vibration, or cutting fluids. Further, the package header must not be damaged; the glass to metal seals must remain hermetic and the seal flange must allow easy rewelding with high leak test yield.

(2) The equipment had to remove lids from packages fast. It should also be easy to set up and use, and to adjust as needed; controls should be few and simple. Eliminating the need to dress the flange after the lid is removed not only saved time, it avoided the potential damage resulting from this manual operation.

(3) Operator safety must not be endangered at any time. Use of sharp knives in manual operations was undesirable. Moving parts especially those designed for cutting, should be concealed. Machining particles should not be allowed to fly toward the operator's face. One way to maximize operator safety was to keep their hands away from the machine through as much of the operation as possible.

(4) Being production oriented meant more than just being fast. Achieving a high volume throughput required a fast process; keeping up the throughput required dependable equipment. Low equipment downtime and maintenance requirements were essential. Minimizing the amount of labor needed and lowering the requisite skill level helped to reduce expenses. Finally, in order to take advantage of the technique at all, the equipment had to be affordable to buy, install, and put into production.

Four Pronged Approach

The approach to the problem involved four major program elements: industry survey, equipment and process development, qualification testing, and implementation.

INDUSTRY SURVEY

First, an industry survey was conducted to gather baseline data on package usage and trends, delidding and resealing techniques being used and their cost and reliability impact, and industry recommendations for delidding and resealing. A mailed questionnaire, followed by telephone interviews and visits to selected companies, provided extensive state-of-the-art information on which to build. This information also served as the basis for selecting the package configurations which offered the greatest potential savings from delidding and resealing. With the package selection made, the best delidding method for that package could be selected and the most promising variation identified and developed.

Response to the industry survey questionnaire was excellent, with 57 companies providing useful information on military hybrids 3/4 inch square or larger (Figure 1).

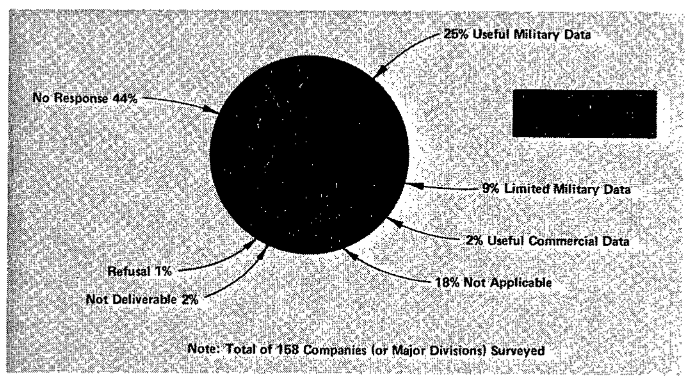

Figure 1

The respondents manufacture 800,000 hybrids annually, with a value of over $240 million. Welded butterfly packages were the most commonly used style, with over 40 percent of the total; welded bathtub packages ranked second, with almost 24 percent (Figure 2). Welded packages in general accounted for over 80 percent of the total. Packages which were approximately 1 in. x 1 in. accounted for more than 66 percent of the response. Soldering and ceramic packages both are on the way out; use of larger packages is in.

Delidding of welded packages by end milling was the most common by virtue of more companies utilizing it, but precision sawing was used on more packages and was the most often recommended method. Welded packages typically could be resealed two times without seriously affecting yields. Soldered package delidding typically was done using a knife, soldering iron, hot plate, or a combination of these; reseal was usually only done once. Cost

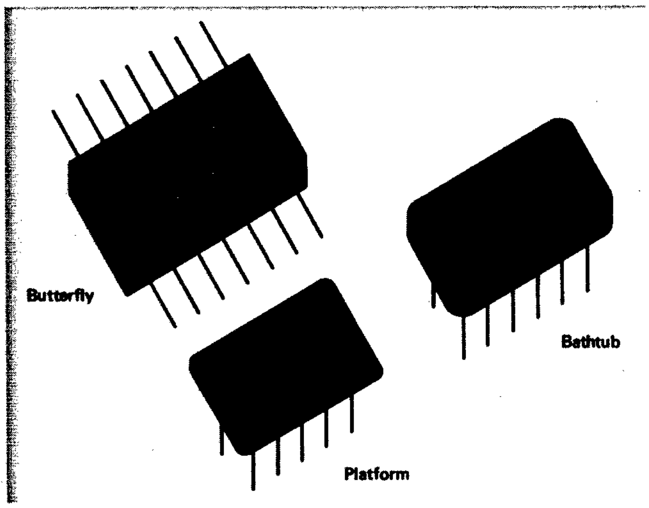

Figure 2

savings from delidding and resealing were reported to be $2.5 million already, but widespread implementation of a technique effective for two reseals was projected to save in excess of $10 million annually.

SELECTION OF PACKAGE CONFIGURATION AND DELID METHOD

Survey data showed that 1 in. x 1 in. welded butterfly packages (Figure 3) were the most commonly used configuration, but the trend was to larger packages. Also, larger packages have more glass seals and a greater possibility for flatness tolerances to be a problem. Since a method developed for the larger package would apply to the smaller one, 1 in. x 2 in. welded butterfly packages were selected. Precision sawing promised to be more effective than end milling at removing lids without affecting the circuit and package, largely because of a newly introduced machine—the Sharp Precision SP100 Microcircuit Cover Remover (Figure 5 and 6). Industry recommendations favored the SP110, and initial investigation supported that choice as the best candidate.

DEVELOPMENT EFFORT

Having selected the package and equipment, necessary equipment development, redesign, and refinement were undertaken. Along with establishing the equipment, the proper technique for using it had to be developed, along with all the necessary process parameters. Optimum parameters and operating tolerances were empirically established.

The SP110 was brand new and needed debugging and refinement to satisfy the goals outlined earlier. Most aspects of the machine's design were at least slightly modified; some major changes were made, also. These changes affected the table, clamp, motor, saw blade, and pneumatic plumbing in an effort to improve the equipment's performance and ease of adjustment and to extend its capability. The operating procedure was modified somewhat. Optimum process parameters and acceptable tolerances were established. Feasibility studies were also conducted on other package configurations, with favorable results.

Machine Operation

Basically, to delid a package the operator first sets the machine for cut width, cut length, and cut depth; the cut width is 10 mils less than the wall thickness, the cut length is simply the length of the package side being cut, and the cut depth is equal to the thickness of the lid (in the weld region). Once these are properly set, the cut width and depth need no further attention. The cut length will be adjusted as necessary to match the side being machined at that time.

Next, the operator places the package face down on the machine's slide table and pushes the package into the reference corner. One edge of the package—e.g., a long side—will overhang the edge of table and be machined momentarily. With the package face down in this corner, the machine is able to make an accurate cut by referencing the top of the package and two adjacent walls.

Depressing the POWER button causes the saw drive motor to start up. Pressing the CLAMP button activates the pneumatic driven clamp to descend, clamping the package to the table. The clamp itself is a pivoting bar designed to distribute the clamping force evenly over the package. Holding down the START button momentarily

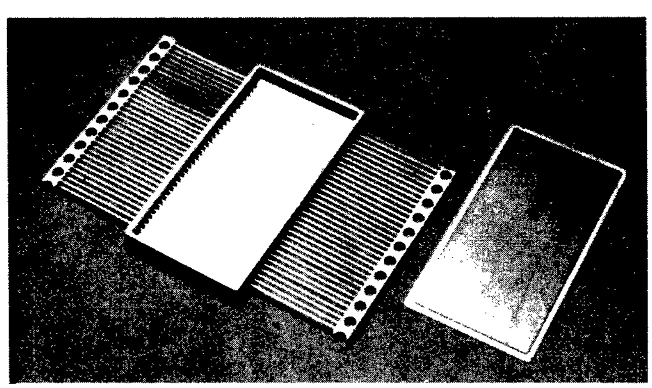

Figure 3

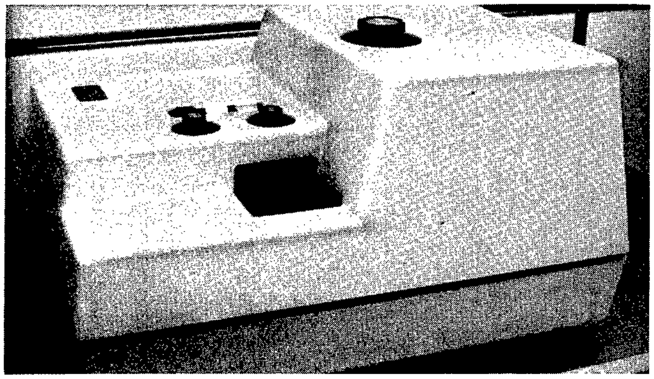

Figure 4

causes the slide table to start advancing the package towards the saw blade. The portion of the package which overhangs the table is machined as the table continues to advance, passing the package over the saw blade. After the entire side has been machined, the table automatically returns.

After one long side of the package has been machined, the operator again presses the CLAMP button, causing the clamp to raise up. The operator rotates the package 180 degrees, clamps the package again, and starts the table. When the second long side has been machined, the operator must make one adjustment before continuing with the two remaining short sides; the cut length must be adjusted for their length. If the package is square, this step is not necessary.

Once all four sides have been machined, the package is removed from under the clamp. When the package is lifted, the lid will remain behind on the table. If the lid is still attached to the package, tapping the package gently on the table will cause the lid to fall free. At this point, the package physically can be resealed without dressing or cleaning the flange. Of course, circuit repair is normally performed first, along with inspection, test, and cleaning. Dressing the flange is not necessary, as a rule; if needed on an occasional package, a knife blade is recommended.

Specific Modifications

As previously mentioned, numerous modifications and redesigns were made to almost all major elements of the delidding machine. Some changes were implemented to improve or extend the machine's performance capability. Others were concerned with ease of operation and adjustment. Still others contributed to improved operator safety. Sharp Precision has incorporated these improvements and others in their new Model SP112 delidder.

Originally, the motor which drives the saw blade was vented inside the fiberglass machine housing. The motor housing exceeded 75 degrees C during operation, while the motor's exhaust warmed everything inside the housing to over 45 degrees C and higher in the direct path of the exhaust air. Heating the precision slide table and other machine elements introduced an unacceptable amount of warping and expansion. Due to the criticality of controlling cut dimensions, any misalignment or instability was disastrous. This thermal instability was mostly avoidable by operating the equipment with the cover raised, but this exposed the operator to the moving parts and caused the perceived machine noise level to increase markedly.

Capping the exhaust on the end of the motor and exhausting air outside the machine housing allows the heated air to be expelled harmlessly into the room. This was accomplished by providing a large hole directly though the motor housing and a matching hole through the equipment baseplate. A gasket provides an air seal between the motor and the baseplate. Solid objects, such as fingers of inquisitive operators, are kept out of the motor itself by a stiff, coarse screen over the hole opening. Only the motor now gets warm; the table and other components remain dimensionally stable at room temperature.

Saw blade chatter results from feeding the package into the path of the saw faster than the blade can easily machine the package away. Of course, if the blade is dull or damaged, chatter occurs easily. Even when the blade is sharp, perfectly round, and mounted tightly to the drive shaft, chatter can occur. If the belt on the drive pulley is not under proper tension, the belt can slip when the blade is trying to cut. Also, if the drive shaft is not properly mounted, vibration can be introduced; this can occur if the bearings are not quite right or if a twisting force is being exerted on the spindle due to misalignment.

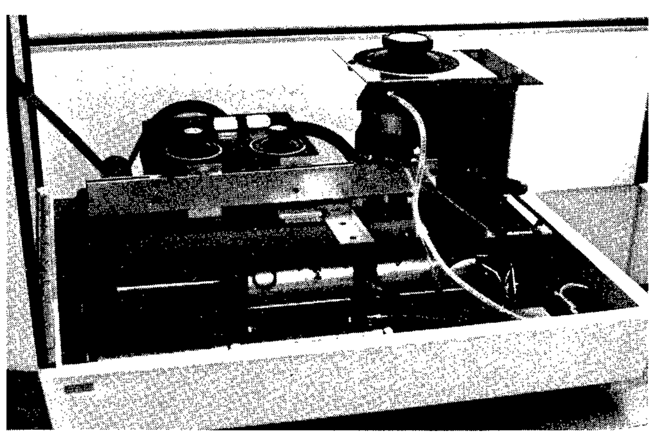

Figure 5

Minimizing the shaft length is another technique for designing out chatter.

One other avenue that was pursued was to improve the design of the saw blade itself. Originally, the saw blade was found to clog up some as it machined away the metal. Kovar is not as free machining as aluminum or most other steels. Changing the rake angle of the saw blade's teeth from 5 degrees to 10 degrees enabled the blade to make a cleaner cut, since the teeth did not hold onto the machining particles.

Shakedown Needed

Several bugs in the pneumatic system had to be worked out. For example, the solenoid controlling the package clamp would intermittently stick, refusing to lower the clamp. Investigation showed that the plunger in the solenoid was able to move far enough that the solenoid did not have the strength to pull it back from that far away. A simple fix was to use washers to limit the plunger travel, eliminating the overtravel. Consistent clamp operation resulted. Accommodating in-between package heights was difficult. Redesign of the height adjustment to a simple, single screw technique allowed easy and continuous adjustment over the entire range.

Another modification implemented for the convenience of the operator was adding a muffler to the vacuum motor. Operators using the machine, also operators in the vicinity, objected to the loud cutting noises and the high pitched whine of the particle collection vacuum motor. Cutting noises were reduced by reducing blade chatter. A baffle network was added to muffle the sound carried in the vacuum motor exhaust.

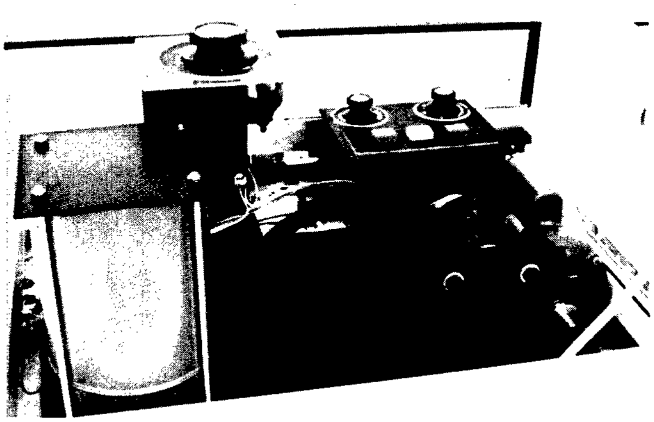

Figure 6

Operator safety was already well thought out in the equipment in order to comply with OSHA requirements in California, the equipment's state of manufacture. Two small plastic covers were added to electrical terminal locations to help prevent short circuiting or electrical shock. Both of these would be difficult with the fiberglass housing closed, but occasionally it was desirable to operate the machine open, such as when adjusting the slide table planarity.

Two changes were made to the table itself. First, the screws holding the main table section down to the slide assembly were changed from flat-head screws to cap-head screws in order to provide better clamping forces with less critical hole drilling. Second, the front stop of the reference corner was changed from a long straight edge to a short straight edge plus a 45 degree slant edge. The slanted edge is used when delidding packages with larger corner radii.

QUALIFICATION TESTS

Proving that the equipment and process were truly effective was the purpose of a rigorous qualification test. Full Mil-Std-883 Class B hybrid screening was conducted on 88 functional hybrids, most of which were delidded and resealed using the methods developed. Electrical, fine and gross leak, and particle impact noise detection (PIND) tests were highlighted, although a full range of mechanical and environmental tests were performed. Some packages were even subjected to moisture and corrosion resistance tests.

Both the delidded and resealed packages and the control packages which had not been delidded performed very well throughout the qualification testing. Virtually every test was passed with 100 percent yields. The only exception worth mention here is that PIND yields were 94 percent and 95 percent, respectively, for the delidded and the control groups. While this is not perfect, the two groups did perform essentially identically and at a very high level. Overall, it was virtually impossible to tell a package that had been delidded and resealed from one that had not, merely by looking at it physically or by monitoring its test performance.

IMPLEMENTATION

Several factors govern how readily a process is implemented. First, the process needs to be established, defined, and proven; this contract has satisfied each of these. Second, the equipment has to be available; the

equipment manufacturer has already increased production in response to the growing number of inquiries stemming from this MM&T contract. Third, the method has to be easy enough for any operator to perform it adquately; it is. Fourth, the cost to acquire and install the equipment must be reasonable; the $10K purchase price of the SP112 and negligible installation cost are easily amortized in a production run, or in a laboratory environment where quantities are lower but hybrid costs are higher. Fifth, the process must be accepted by the industry; the favorable response evident to Westinghouse, Sharp Precision, and to the Army and Navy sponsors seems to indicate the obvious and substantial benefits to be accrued by implementing this technology.

When manufacturing hybrids for military applications, it is necessary to have more than just industry acceptance; the appropriate military specifications must allow the procedure. This is the only major obstacle remaining in the path of widespread implementation of the delidding and resealing technique developed under this contract. Westinghouse has proven out the technique to their own satisfaction and to the satisfaction of many other companies. Both the Army and the Navy sponsors have expressed their satisfaction, also. Westinghouse has been keeping the cognizant Government agency notified of progress on this contract and the intent to petition for approval of this delid/reseal method. A formal petition will be filed; supporting evidence will be collected and submitted as other companies implement this technology by waiver.

Internally, Westinghouse has implemented this technology on all applicable programs, again, by waiver. New hybrid designs are increasingly utilizing package configurations which can be delidded and resealed per this method. One entire line of specially designed packages which are now solder sealed has been modified to enable welding, allowing delid/reseal as necessary per the method developed. Use of soldered ceramic butterfly packages will decline in order to take advantage of the delid/reseal capability afforded by welded metal butterfly packages via the technique described.

ADDITIONAL EFFORTS

Multiple Reseals

Qualification testing was done only on packages which had not been delidded, or had been delidded and resealed once. During the development effort, however, some packages were delidded and resealed several times. This was done partly to investigate the cumulative effect of machining errors and imperfections, and partly to see how many times a hermetic seal could be achieved on a single package. An example of a multiple reseal was included earlier with the weld cross sections.

Machining anomalies—whether they be due to the package being warped, the machine being out of adjustment, or to the operator not doing something quite right—create a practical limit on how many times a package can be delidded and resealed in a normal production environment. One reseal is not difficult to achieve; two reseals are possible; three reseals require the operators to be paying attention to what goes on each time. In an engineering environment, such as in a prototype laboratory, additional reseals can be achieved if proper care is taken each time. This is particularly true if the package is designed with the glass seals well away from the weld flange and if the package has enough internal clearance to allow loss of a few thousandths of an inch wall height, if necessary.

Other Package Configurations

Limited testing was conducted on welded package configurations in addition to the butterfly package. Specialized packages bearing some resemblance to butterfly packages were delidded and resealed, as were nonrectangular butterfly packages and bottom-pin bathtub packages. Each of these package configurations was tested only for delid/reseal feasibility; full qualification testing was not performed.

While the delidding approach developed was intended only for welded packages, some attention was given to soldered packages. Since the delidding operation typically resulted in bare Kovar being exposed, fluxless soldering would be virtually impossible for resealing. If the complete solder joint were removed, however, the resultant exposed Kovar seal flange could be weld sealed. Soldered bathtub packages were used to investigate this, although butterfly packages could have been used just as appropriately.

Amending MIL-Spec Can Save Money

Delidding and resealing is becoming increasingly important as a rework technique. And, as previously mentioned, survey responses indicate savings due to delidding and resealing are presently $2.5 million per year and could exceed $10 million annually if a successful delid/reseal method received widespread implementation.

Implementation has occurred at Westinghouse and is under way at other companies. Full scale implementation will be enhanced if the effort to amend Mil-M-38510 to allow delid/reseal per the method described is successful within a reasonable time span.

A Look Into the Future

Real Time Ultrasonic Imaging

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With increasing complexity of structural design and the usage of advanced materials, a need exists for better inspection techniques and technology. Under a project for the U.S. Army Missile Command, General Dynamics (Convair Division) and Battelle-Pacific Northwest Laboraories jointly undertook a project to assemble a real time ultrasonic imaging system (RTUIS) in breadboard form and to demonstrate its potential for production line nondestructive inspection of fiber laminate or metallic structures.

Traditional Methods Inadequate

The evaluation of the quality of a production line item is an essential and significant part of the production process. Often, the factors affecting quality can only be detected using radiation that passes through the material of which the part is made. The most common forms of penetrating radiation are X-rays and ultrasound, although beams of particles such as neutrons can be used for some inspection tasks. Gamma rays, especially those generated by the radioactive decay of Cobalt 60, are used in the inspection of large metallic hazards associated with X-rays and nuclear particles. More often, an ultrasonic method is chosen because it is uniquely effective for detecting the type of defect that is likely to occur. Delaminations in layered structures may be used as an example. A delamination represents a very distinct and sharp discontinuity and is a strong barrier for the transmission of ultrasound, but unless seen edgewise, is usually undetectable by X-ray or other methods of nondestructive testing using ionizing radiation.

NOTE: This manufacturing technology project that was conducted by General Dynamics and Battelle-Northwest thru the U.S. Army Missile Command was funded by the Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Al Marsili (205) 876-2147.

Standard production line ultrasonic testing methods use a transducer that scans the item, generating an echo whenever a void volume or inclusion is encountered in the otherwise uniform volume of the piece being examined. This approach requires a simple geometry and does not provide an image of the part being examined. To provide an image, specialized scan techniques have been developed that generate either a cross-sectional view (B-scan) or a plan view (C-scan) of the piece. These specialized scan methods are normally too slow to permit 100 percent inspection in production line situations. They build up an image a point at a time or, at most, a line at a time.

Both New and Old Ideas Lead to Solution

The solution to the problem as conceived by General Dynamics and Battelle combines a number of new and old ideas into a viable package. One of the new ideas uses the blinding speed of present day microprocessors to create a real time environment for the inspection system. Their speeds can be used to digitize video images, then to eliminate or greatly reduce the background noise while enhancing the contrast between the defect and its neighboring vicinity by integrating the defect's image over a number of image frames. Another idea uses an isometric projection to give a three-dimensional appearance to the flaw in a video display. The x and y directions give the cross-sectional region containing the flaw. The z direction gives the magnitude of the distortion of the impinging ultrasonic energy at the flaw, caused by either absorption or reflection. The other major idea adapts an existing liquid surface inspection system that creates the flaw's image by means of acoustical holography.

The technical approach was to acquire the necessary microprocessors and digital electronics hardware and integrate them into the existing liquid surface inspection system. Elements which already existed and could be incorporated as is included the mainframe, collimating lens, pulsed light source, imaging lens, video camera, real time video monitor, and video tape recorder. Elements which exist but require modification were the electronic control and sequence timer, imaging tank, optical beam control prisms, and spatial filter.

New elements to be added to the system included an integrated display monitor, a digital image processor, a hard copy printer, and a mechanical scanner.

The manner in which these basic elements were created and integrated into one functioning RTUIS system is shown in figure 1. The existing liquid surface inspection system provides the mainframe, lenses, prisms, light source, and basic video equipment. It also includes the electronic control and sequence timer, but this circuitry will be modified to operate at a higher pulse rate. The existing imaging tank will be replaced with one that responds uniformly to a broader range of ultrasonic frequencies and is more stable against corrosion, temperature changes, and fluid level. Similarly, the optical beam control prisms and spatial filter will be redesigned for firm, stable operation in a production environment.

The effect of these improvements to the existing system is an improved basic system. Other elements must be added to this improved basic system to achieve the operating capability of the RTUIS. Two of these, the hard copy printer and the integrated display monitor, are purchased items. The digital image processor and the mechanical scanner must be designed and fabricated. Both of them will be designed to create flat, rolled out images of cylindrical objects. Other shapes can also be imaged in the system, but each type of object requires specific insonification arrangements such as frequency, pulse width, pulse delay, adjustment of acoustic lenses, design of ultrasonic transducer, etc. The image flattening feature included in the digital image processor will be switched out when noncylindrical objects are being imaged.

Holographic Images from the Liquid Surface Inspection System

The liquid surface inspection system is a good choice to be the fundamental building block in RTUIS, because it permits digitization and reconstruction of the flaw's image from the intermediate hologram. A composite block with holes drilled in one end ranging from 0.5 mm to 3.0 mm in diameter is shown in Figure 2 (top). The ultrasonic image in figure 2 (bottom) clearly shows the depth each hole was drilled.

Figure 3 shows a steel cylinder with wall thickness of 0.125 inch and a hole drilled lengthwise into the shell with

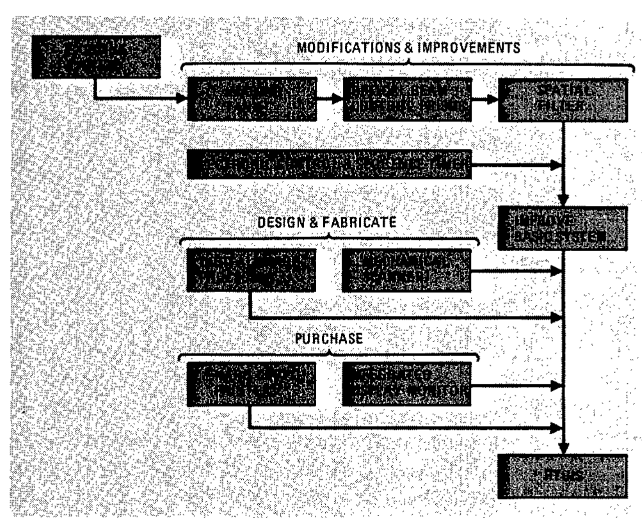


Figure 1

a 0.120 inch diameter. The imaging was done at 3 MHz to reveal the depth of the drilled hole.

Acoustical holography has been demonstrated, both theoretically and in practice, to have the highest resolution of any acoustic instrumentation available. Acoustical holographic systems are a factor of two or higher in resolution than any other imaging device because of their simultaneous source receiving scanning capability.

Resolution with Longitudinal and Shear Wave Illumination

Acoustical holography imaging techniques have been extremely successful using longitudinal and shear wave illumination to image flaws deep within metallic sections. The following results have been included to briefly review some of the basic resolution capabilities in both longitudinal (L) and transverse or shear (S) wave holography.

Figure 4 shows a "Y" pattern geometry with respect to an aluminum block. One branch of the "Y" contains holes separated edge to edge at the resolution limit of 2 mm at 2.6 MHz. The hole separation of the other two branches

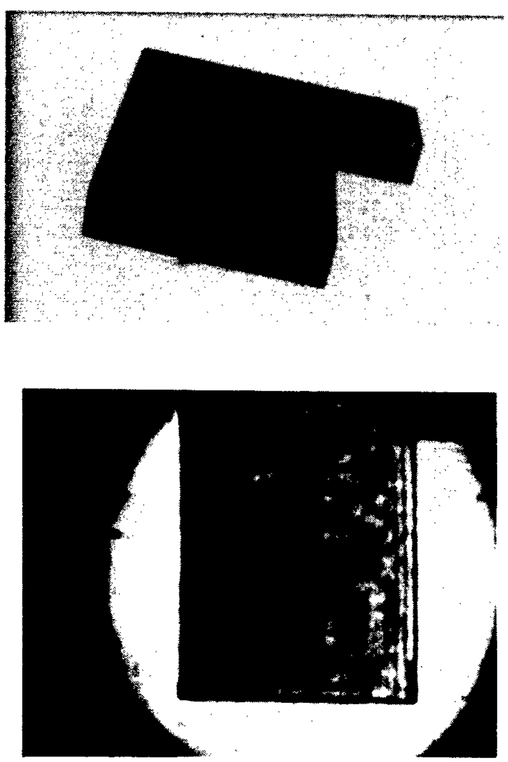


Figure 2

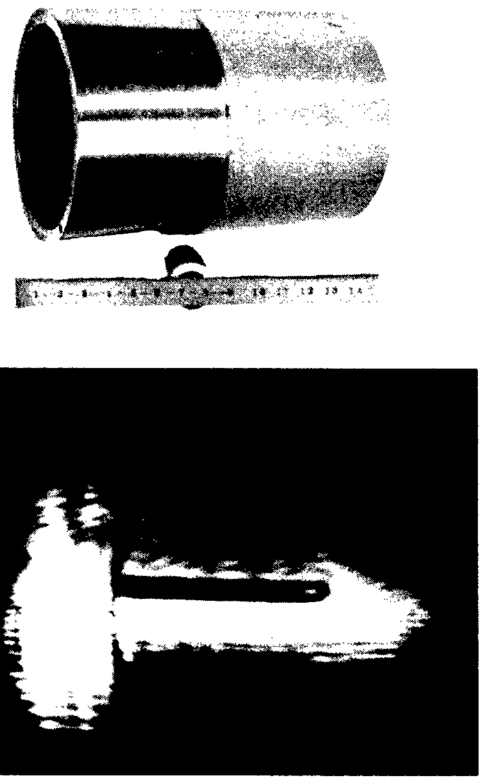


Figure 3

are 4 mm and 8 mm, respectively. The three dimensional drawing indicates the observer's view of the holes with longitudinal wave illumination.

The hologram and reconstruction image is shown in Figure 4 (bottom). The image shows the 2 mm separated holes to be resolvable, but very close to merging together. The hole separations at 4 mm and 8 mm are easily resolvable in the two rightside branches.

An example of shear wave resolution is shown in Figure 5. Seven flat topped holes are drilled on the diagonal block surface. The holes are 6.4 mm in diameter and placed in a "Y" pattern. The hole spacing in the first row is 2 mm edge to edge; second row is 3 mm edge to edge, and third row is 4 mm edge to edge. The reconstructed image resolves the 2 mm edge to edge holes.

Key System Requirements

Certain key features were specified for incorporation into the new advanced real time ultrasonic imaging system. It was specified that the system should include the following capabilities:

- Production of a real time video image/printout
- Capability of contrast enhancement/flaw detection in real time
- Capability of pattern recognition/defect decision language
- Quantitative measurements of defects that are simple and rapid
- Inspection of complex geometries
- Summing of frames to reduce signal noise in semi-real time
- Filtering and smoothing to improve flaw recognition
- Storing of image on magnetic tapes for retrievable processing or reinspection
- Capable of presenting a full three dimensional image of the defect regions instantaneously
- System that is production oriented.

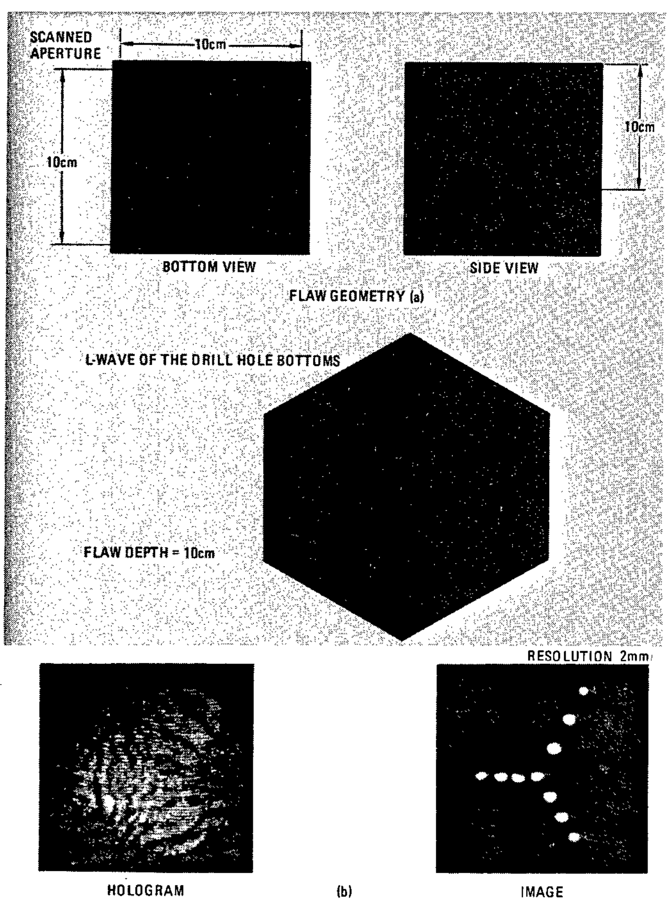


Figure 4. Longitudinal-Wave Resolution Geometry Hologram and the Reconstructed Image (2.6 MHz)

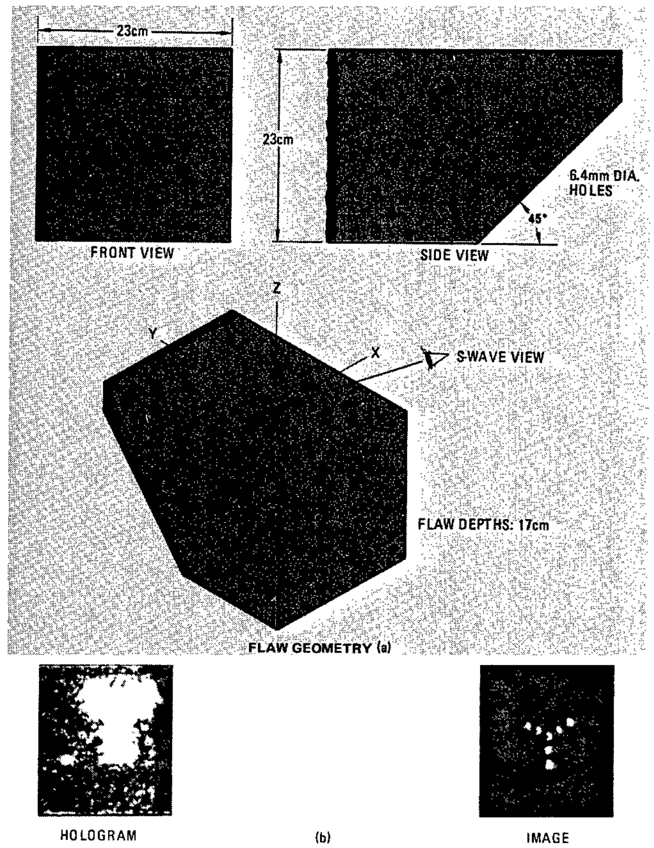


Figure 5

Breadboard Real Time Ultrasonic Imaging System

Battelle has many years of experience in applying ultrasonics to nondestructive examination of industrial and military components. Included in this experience is the development of unique imaging systems based upon the principles of isometric display and the principles of ultrasonic holography. The type most suited to meet the requirements of the manufacturing methods and techniques for real time ultrasonic imaging uses a liquid surface as a detector of ultrasound and as the interface between ultrasound and light. A schematic diagram of this system is shown in Figure 6. Sound generated by the object transducer interacts with the object. The interaction encodes information about the object on the ultrasonic wave, which sometimes is called the object wave or object beam.

Characteristics of the object are encoded into the ultrasonic wave by absorption, refraction, diffraction, and reflection. Lenses L1 and L2 image the object into a liquid surface detector. Disturbances in the object tank caused by moving the object are prevented from propagating to

panded to fill the aperture of a collimating lens mounted above the liquid surface hologram. The light is diffracted and reflected by the grating impressed upon the liquid surface by the interfering ultrasonic beams. A collimating lens focuses the reflected light in the plane of the spatial filter where only first order diffracted light is transmitted to the video camera. The video camera is focused on the liquid surface as seen through the collimating lens. The end result is that the object is seen on the video monitor.

The system shown in Figure 7 is uniquely suited to serve as the starting point for the advanced real time ultrasonic imaging system (RTUIS). It has an object field up to five inches in diameter. Normally, the system is adjusted to image a 2.75 x 3.5 inch field with resolution into 4,000 picture elements (linear resolution of 0.040 inch). The system forms a complete picture of this field in 0.0001 second. Allowing five milliseconds delay time between pictures, the system can deliver 200 pictures per second This high rate of image formation is the salient feature of this system.

Video Image Processing Equipment

Slit Camera. The slit camera (Figure 8) was built to record objects moving across the field of view of the ultrasonic imager at a uniform rate. It consists of a camera lens mounted in a dark enclosure. At one end of the enclosure is a small rectangular opening past which the film moves as a picture is being taken. The film is driven along a track at a speed that matches that of the image formed by the camera lens. A video monitor is positioned at the other end of the enclosure. The image on this monitor is relayed at

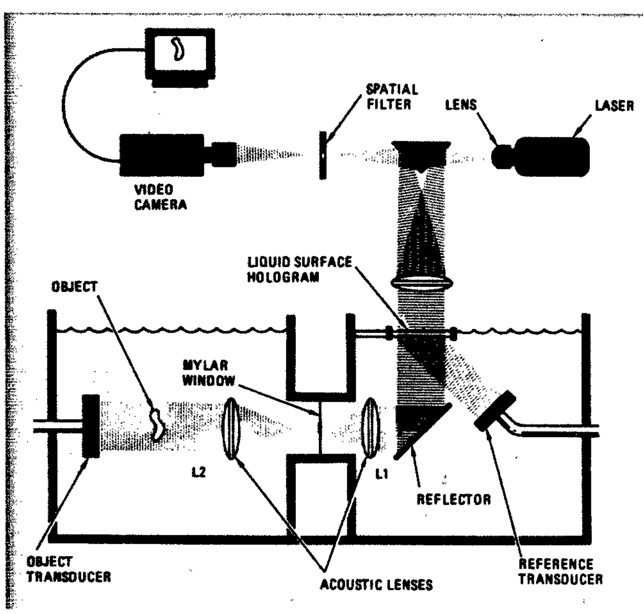


Figure 6

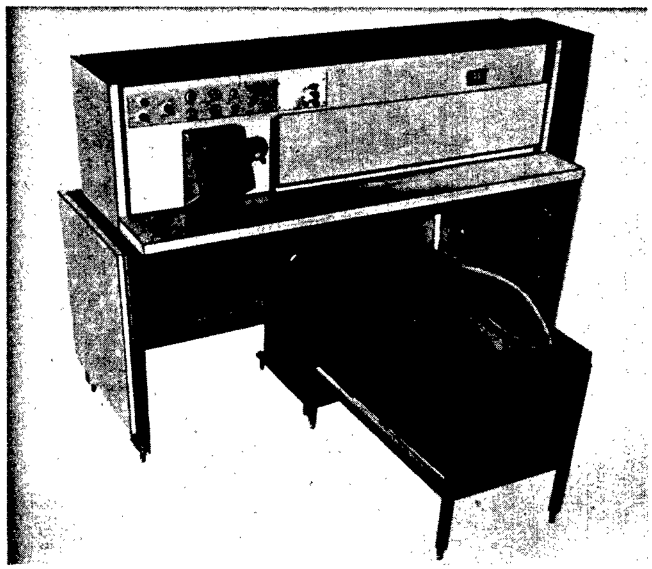


Figure 7

0.4 x magnification to the film plane by the lens.

This camera was built for the purpose of demonstrating that the background pattern generated by the reference and object sources could be eliminated by frame summing as the object moves through the field of view.

Image Processor. A real time digital image processor was used to assess the effects of frame averaging. Frame averaging to remove reference and object source diffraction (near field) patterns was implemented by oscillating the two ultrasonic sources a few degrees about an axis parallel to their surfaces while doing a 32 frame average. The ability to average any number of frames from 2 to 128 in real time is a unique feature of this equipment and is very effective in smoothing background irregularities arising from near field patterns, coherent speckle, and interference effects.

The processor in its present configuration can deal only with objects that are stationary in the field for the period required to develop an 'N' frame average. That period is one half second when N is 32 frames.

Video Analyzer. A video analyzer was used with the RTUIS breadboard to provide an accurate measure of video output levels. Accurate knowledge of the output levels is essential for setup of automatic defect decision criteria. The video analyzer acts as a sampling scope. It displays vertically line selected video waveforms directly on the screen of the same video monitor used to display the image. The display includes in electronic reference grating with horizontal and vertical markers which facilitate quantitative readout of video levels in easily identified regions of the image.

Video Detector. In the RTUIS breadboard a video detector was used as a defect decision device. Whenever the video signal drops below and/or rises above preset limits, this device provides an automatic warning signal. In the RTUIS prototype, a second type of defect decision device will be added. A dc voltage proportional to the integral of the video signal falling within a selectable window area will be generated. Since delaminations become dark areas in the video display, the dc voltage level will be a measure of the area of the defect. Whether or not a given defect is acceptable or unacceptable therefore can be decided automatically on the basis of the voltage level.

Isometric Processor. Gray level can be treated as a third or z-dimension, which together with the z,y,z position characterizes a video image pixel in terms of three coordinates. By rotating the coordinate system in which this type of video image is viewed, useful enhancement of the video image is obtained. The image is presented as an isometric projection on a CRT display.

In the RTUIS breadboard, the isometric processor was used in three different ways. The raw unprocessed image could be displayed directly upon the x,y,z monitor. This mode of use was effective in emphasizing the passage of a flawed area through the field of view, but was difficult to capture in a still shot. A second mode of use resulted from using a frame summed image (such as that produced by the slit camera) as the input to the isometric processor. The image then can be rotated and tilted so that the delamination region appears to be a flat topped mountain in the field of view. This mode will be most effectively utilized in the RTUIS prototype, where the scrolling digital memory replaces the slit camera. The processed image then will be directly available as an input to the isometric processor.

A third mode of operation will also be available whereby the video signal passes through the isometric processor

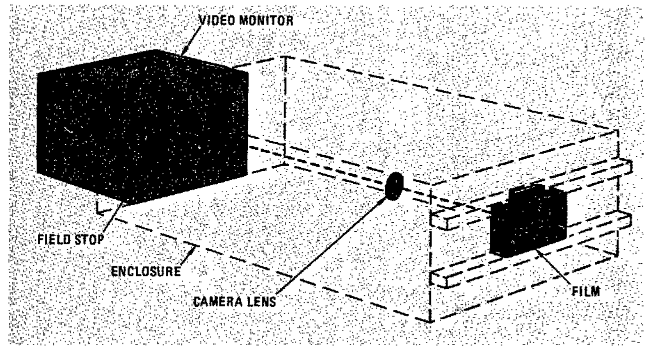


Figure 8

before being applied to the slit camera. To be effective, only a small amount of tilt and no rotation is used.

Performance Evaluation

Evaluation of the performance of the RTUIS breadboard system was based upon its ability to image test patterns and flaws in a variety of objects including the following:

- Viper launch tubes
- Viper rocket motor casings
- Castings
- Weldments
- Aluminum, steel, and nylon plates
- Graphite epoxy structures.

To test the resolution of the imaging system, holes were drilled in a one half inch thick nylon plate. Two types of patterns were used as illustrated in Figures 9 and 10. In Figure 9, the holes are imaged with their axes parallel to the direction of the sound, while in Figure 10 the sound path is perpendicular to the axis of the holes. Using the 'Y' pattern, the resolution is adequate to reveal that holes

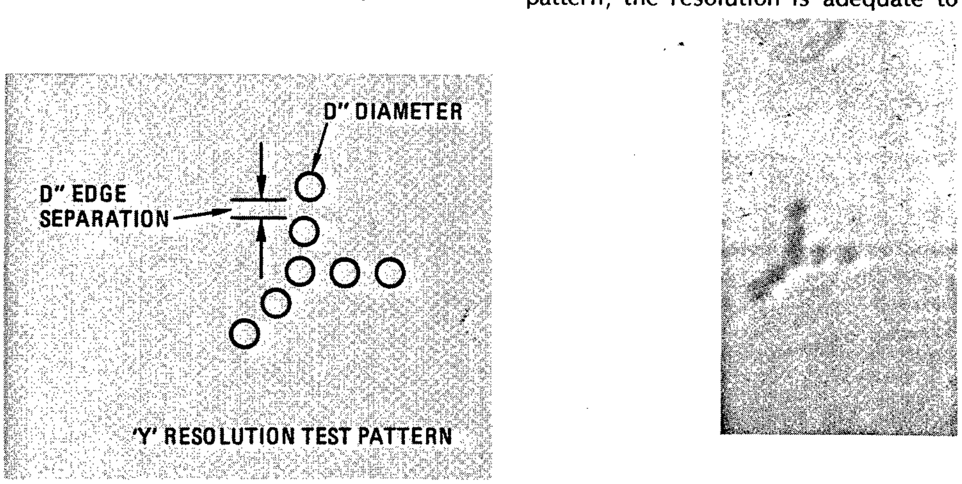


Figure 9

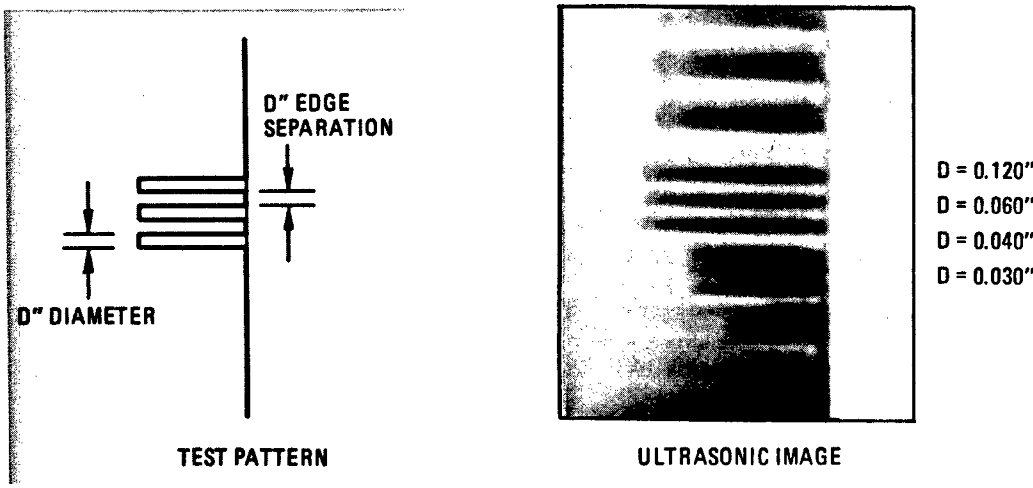


Figure 10

the liquid surface hologram by a Mylar window. A reflector turns the axis of the beam 90 degrees and directs it to a small tank having a thin plastic bottom through which the ultrasonic beam propagates to the surface of the thin layer of liquid. Ultrasound from the object beam reaching this surface is mixed with ultrasound from a reference transducer to create a liquid surface diffraction grating or hologram.

In order to read out this hologram, it must be illuminated with collimated light from a coherent source. Light from a pulsed argon ion laser is focused and then ex-0.060 inch in diameter spaced 0.060 inch apart edge to edge are separate and distinct.

In Figure 10, where the axes of the holes are perpendicular to the path of the sound, patterns with a characteristic dimension D of 0.030 inch are resolved.

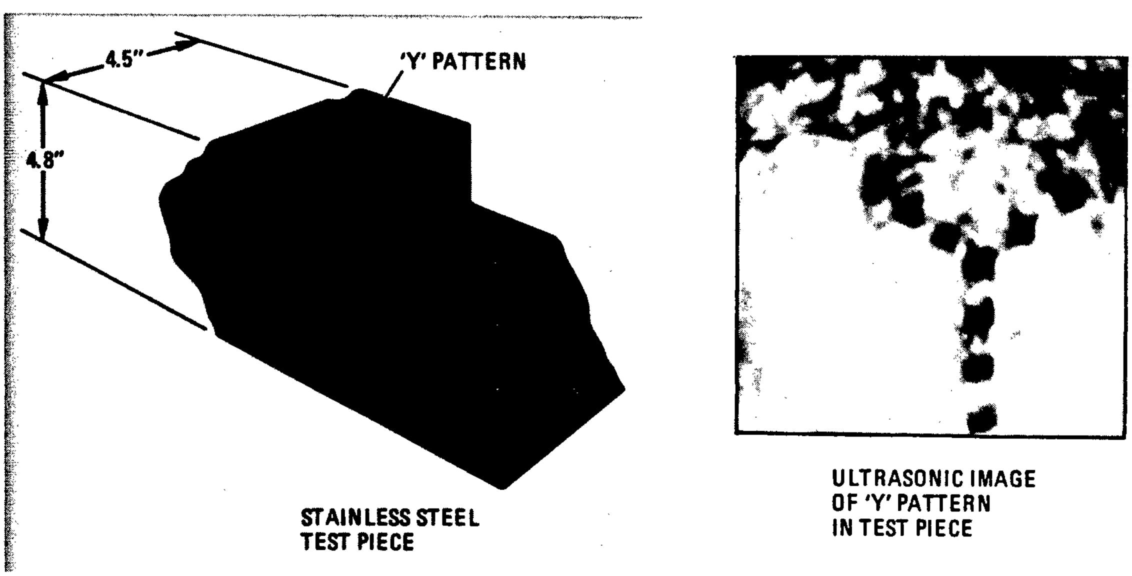


Figure 11

Images of Some Test Specimens

Images generated during this work were produced with the ultrasonic system operating at 5 MHz frequency. The one exception was the image of the large austenitic steel block, which was imaged at 3 MHz.

Figure 11 shows an ultrasonic image (3 MHz frequency) of a 'Y' pattern viewed through 4.8 inches of austenitic steel. Each hole in the 'Y' pattern is one eighth inch (3 mm) in diameter. Hole spacings vary from 0.137 inch for the short leg of the 'Y' to 0.216 inch for the long leg. Frame summing was essential to produce a clear picture of these holes. Approximately 30 frames were averaged while the object beam sound source was oscillated. The picture demonstrates the power of frame summing for removing coherent speckle and bringing out image detail. With no sound source wobble, coherent speckle completely obscures the 'Y' pattern. Wobbling the sound source causes the coherent speckle pattern to move about so that an average of 30 image frames produces a clean background, leaving only valid object structure in the image.

A slit camera picture of a Viper rocket motor casing is shown in Figure 12. Figure 12a records the normal structure with no defects. The rocket motor casing has a rough surface, which in itself obscures fine detail within the structure. In these images, the axis of the motor is vertical. The circumference has been laid out flat and each picture records approximately half of the circumference. In Figure 12b, a piece of the aluminum liner 0.2 inch square has been removed by grinding. The grinding extended beyond the aluminum liner into the fiber glass epoxy material. A circle identifies the ultrasonic image of this region; presented in this manner, this flaw could easily be missed. Using gray level slicing provided by the image processor and video detector, the flawed region can be recognized as the brightest area in the image. Figure 12d was produced by feeding the level sliced image to the slit camera. The resulting picture seen on the video monitor and recorded by the slit camera leaves no doubt as to the location of the flawed area.

Detection of another type of flaw is illustrated in Figure 12c. Here a delamination induced by a hammer blow is clearly imaged as a dark semicircle in the lower center of the picture.

Next Step—Build Prototype

The component requirements for a real time ultrasonic imaging system (RTUIS) have been established, and a breadboard system has been assembled. Imaging of flaws was demonstrated using Viper launch tubes, Viper rocket motor casings, heavy austenitic steel weldments, and aluminum squeeze castings. For removing background patterns of ultrasonic transducers and speckle arising from the coherent nature of the ultrasonic wave, frame summing and averaging was shown to be effective. The next step is to build, test, and demonstrate the RTUIS prototype system. This work should begin as soon as possible to gain the economies of continuity of effort and to realize the benefits of 100 percent production run inspection as early as possible.

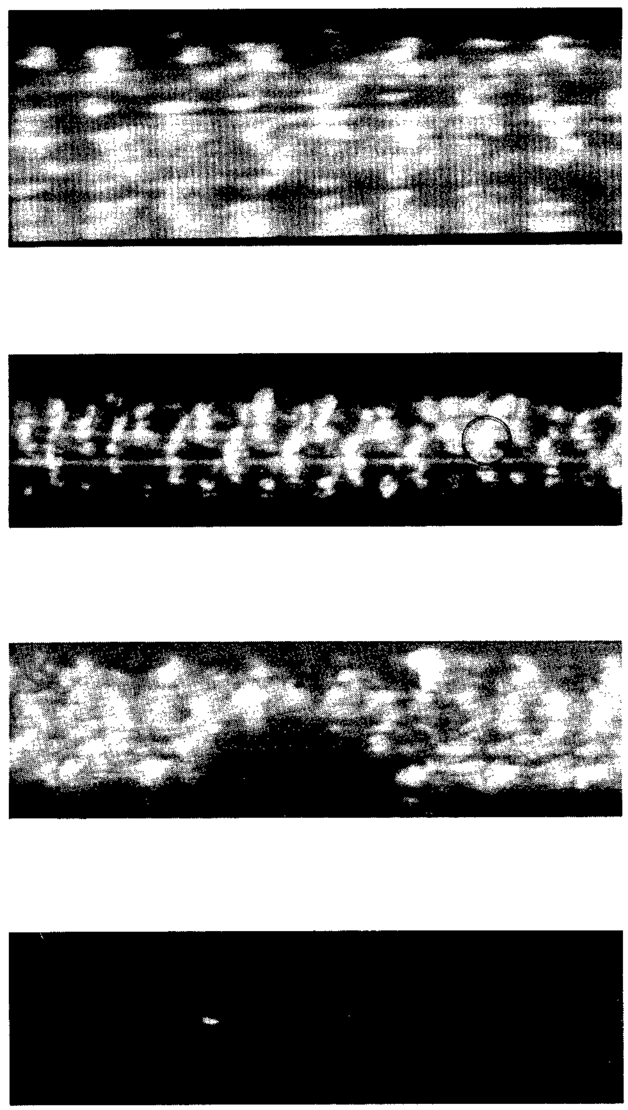


Figure 12

Brief Status Reports

Project 7113, AVRADCOM. Composite Rear Fuselage (CRF) Manufacturing Technology. All tool proofing components have been fabricated, assembled, and installed in the ground test vehicle. Static tests were conducted and demonstrated achievement of design limits. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7119, AVRADCOM. Nondestructive Evaluation Technic for Composite Structures. State of the art reviews covering radiography, ultrasonics, and acoustic emission techniques are in process. Samples from the IMRB were characterized by FTS-IR. Additional piezoelectric polymer acoustic emissions were received. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7156, AVRADCOM. Ultrasonic Assisted Machining for Superalloys. Project continues to await availability of suitable equipment at Corpus Christi Army Depot for machining trials. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7202, AVRADCOM. Application of Thermoplastics to Helicopter Secondary Structure. The request for additional funding was approved. All inner and outer skins for the access door have been fabricated and are ready for assembly. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7241, AVRADCOM. Hot Isostatic Pressed Titanium Castings. The cast material as presently processed is not suitable for application to critical dynamic components such as the UH-60A main rotor hub. It was decided to minimize expenditures until problem is fully explored and a decision is made to redirect or terminate. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7288, AVRADCOM. MMT Determination of Optimal Curing Conditions. Processing cure analysis including ion graphing, acoustic emission, and thermography F/reinforced laminates of EM SP-250 DEG F cure and NARMCO 5208 350 DEG F cure prepregs is nearing completion. Laminates of 14, 28, 56, and 112 plies are being tested. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 5071-74, TECOM. Smoke Sampling/Characterization. Data was collected from 40 wind tunnel tests with FOG/IR Materials. Tests have been initiated to eliminate problem of mounted sampler movement. The final report has been submitted and approved for publication. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 5071-78, TECOM. Automation of Analysis of EMI data. The format for inputting EMI Data was established. Time-to-cost estimate for FAEF Data to the computer data base was determined. The feasibility and cost data tape vs. modem input were evaluated. Use of tape input was done. The interface requirements were ident. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 5071-80, TECOM. Computer Aided Test Planning. The initial drafts have been completed for the methodology report. The final report was submitted to headquarters TECOM and is pending approval. The plan is fully operational as the central tool for producing USATTC detailed test plans. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 5071-01, TECOM. Acceptance Test Procedures. The central library for the total ATP Program was maintained. The ATP index supplements were published and distributed. The master ATP index was published and distributed. Regular distribution of ATP's was made in accordance with TECOM reg 700-9. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 7036, AVRADCOM. Isothermal Roll Forging of Compressor Blades. Test blades must be reworked before root machining. After rework and evaluation, blades will be tested at AVCO. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 1318, ARRADCOM. Chemical Production Fill, Close and LAP for 8-in. XM736 Project. This project is completed. Final status report received. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 6350-2431, AMMRC. Computerized Color Matching System. The evaluation of the two units has been completed . It was concluded that the units are 5 times more reliable than human observers. A final technical report is being prepared. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2444, AMMRC. Ultrasonic Testing of Roadwheels. Due to the time requirements to complete the road testing, a second contract extension has been executed at no cost to the Government. A second piggyback road test of the roadwheels has been completed for a total of 5260 test miles. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2446, AMMRC. Blacklight Video Inspection System. Procurement action to acquire an automatic black light video inspection system was taken. The scope of this effort has been scaled down. Many of the automatic features have been eliminated. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 1295, ARRADCOM. Modernization of Charcoal Filter Test Equipment. The design of the containment chamber was finalized and the Level 1 drawings completed. A modular panel type assembly was proposed to facilitate shipment and reconstruction. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 3592, MERADCOM. Improved Graphite Reinforcement. Optimization of the oxidation and carbonization processes is complete. Tensile properties were shown insensitive to oxygen content of the fiber, but they were improved by higher carbonization rates. For additional information, contact Emil York, MERADCOM (703) 664-5872.

Project 3708, MERADCOM. Coated Fabric Collapsible Fuel Tank Program—Circular Seamline. Seamless fabrics coated at contractor facilities. Coating operation accomplished with difficulty. Coated sleeves fabricated into tanks. Mounting of patches for hardware and sealing of end seams proceeded slowly but satisfactorily. Testing begun. For additional information, contact Emil York, MERADCOM, (703) 664-5872.

Project 3709, MERADCOM. Continuous Length Fuel Hose. All work has been terminated. Continuous length fuel hose is now available commercially at considerably lower prices than previously used hosing. A final technical report is being prepared. For additional information, contact Emil York, MERADCOM (703) 664-5872.

Project 7605, ARRCOM. Chemically Bonded Sand For Close Tolerance Casting. The small core sand system was checked out and the layout was improved. A floor mounted crane was added for convenience to the workers. Plans for large molding system complete. Some green sand equipment dismantled and/or removed. Most new equipment received. Pits almost complete for new shakeout and reclaimer units for chemically bonded sand. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7707, ARRCOM. Automated Process Control for Machining. Software for an interactive computer procedure is being developed to aid the selection of machining conditions. Needs exist for NC programming, industrial engineering, methods and standards, and various levels of management. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7724, ARRADCOM. Group Technology of Weapon Systems (CAM). A computer aided process planning program was developed and tested. The software is currently being revised. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7730, ARRCOM. Manufacture of Split Ring Breech Seals. Modifications to kinking unit continue. Technical proposals for ring splitting equipment were evaluated and accepted. Step 2 of 2-step procurement action is under way. Construction of a polishing fixture is in process. Preliminary testing of the kinking unit revealed several weak areas in the machine construction. Modifications are under way to correct these areas. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 3749, TACOM. Hydraulic Rotory Actuators. Original actuators tested. Four additional actuators were completed and tested. Producibility plan and critical item specs have been delivered. Top is complete pending an ECP to make minor modifications. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 6350-2450, AMMRC. Gun Steel Adhesion Chromium Coating Measurement. The ultracentrifugal adhesion test assembly was recovered, inventoried for completeness of the various subassemblies, and delivered for modification. Delivery of the completed system is scheduled for October 1983. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 4264, TACOM. Track Inserts and Filters for Track Rubber Pads. Torsion test machine now completed and installed. Qualification testing is under way. A final report is being prepared. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 4575, TACOM. Laser Welding Techniques for Military Vehicles. Production mockup using military turret ring casting to inner turret wall completed. Ballistic test plates prepared. Testing preformed and preliminary results positive. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 1042, MICOM. Production of Composite Radome Structures. Efforts to produce the full-scale radome are under way. Part design and tooling design and fabrication are nearly complete. In-process quality control procedures are being evaluated. Option on contract has been extended (two layer radome). For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1050, MICOM. Low Cost Braided Rocket Motor Components. The full scale motor concept and reproducibility demonstrations have been accomplished. Delivery of production components for test firing is under way. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 6350-2613, AMMRC. Inflow air Bleed Test, LTC-712 Engine. The project was re-evaluated regarding progress to date, objective and funds. It was determined what funding would be required to complete the project. As a result of this project re-evaluation, AMMRC funded the effort. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2614, AMMRC. Temperature Compensated Voltage Cont. Crystal Oscillator Test Methodology. The Government has accepted the final revised methodology and test procedure for evaluting the frequency stability of temperature compensated voltage controlled crystal oscillators. The contractor started testing crystal oscillator. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 1907, ARRADCOM. Automated Gaging for Medium Caliber Projectile Bodies (CAM). The work effort centered on the completion of the prototype gaging system to characterize the features of the forward fuse mating threads. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 7201, ARRADCOM. Artillery Weapon Firing Test Simulator. This project is complete. A final report is being prepared. For additional information, contact Dennis Dunlap, ARRADCOM, (309) 794-3270.

Project 7580, ARRCOM. Pilot Automated Shop Loading and Control System-CAM. All modules are operational and being used. Work is in process to plan and schedule critical components for the other major items. The project is complete; for additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 5071, TECOM. Smoke Obscuration Test Procedures. The technical approach for the measurement of smoke obscuration/attenuation was established. In addition, the requirement necessary to acquire equipment and instrumentation was also established. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 5071-60, TECOM. Receiver Operating Characteristics Measurements. The first phase of the ROC Methodology Investigation has been completed which included technical review, instrumentation requirements, and procedures. The investigation is in suspension until the equipment is purchased through the instrumentation acquisition. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 0900, ARRADCOM. Automated Multiple Filter Life Tester. Two techniques for dispersing a chemical agent were developed. One utilized a piezoelectric crystal to vaporize the agent. The other used a thermal resistor to disperse the agent. A bellofram diaphragm pump was developed as a simulated breathing device. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 0905, ARRADCOM. Manufacture of Impregnated Charcoal-Whetlerite. The scope of work for contract effort was completed. The procurement request package has been submitted. For additional information, contact Donald Fischer, ARRADCOM (201) 724-5957.

Project 0913, ARRADCOM. Spin Coating of Decontamination Agent Containers. Contract awarded. Technology and engineering evaluations conducted. Application techniques are being evaluated. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 1335, ARRADCOM. Manufacturing Techniques for New Protective Mask. Pilot production line installed and production of individual components under way. Prototypes of alternate faceblank material being fabricated. Top is complete. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 1060, MICOM. Electrical Test and Screening of Chips. Teledyne is identifying chip testing methodologies. Applicability of baseline system is being evaluated. Process model evaluates temperature of a silicon chip as a function of time and location. Data is being collected on air flow wear chip. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1072, MICOM. Multiple High **Reliability/Low Volume LSI Manufacturing (CAM).** Work has been completed on the industry survey, processing plan, photoresist processes, mask inventory handling, wafer etching, patterning, multi-source doping, diffusion, chemical vapor deposition and process CAM, for making ICS. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3532, MERADCOM. Molten Salt Lithium-Chloride Battery. Prototype cells built for a 30-cell 12KWH 36V battery continue to show excellent life cycle characteristics. Average of 370 cycles thus far. Selection of 30 cells for MERADCOM BATTERY COMPLETED. Cell data indicate excellent chance of achieving 300 CYS. For additional information, contact Emil York, MERADCOM, (703) 664-5872.

Project 6350-2422, AMMRC. Inspect/ Meas Method forSphericalSurfaced Components. The fabrication of the test equipment was completed. The profile plates have been evaluated by an independent laboratory technique at ARRADCOM. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5019, CORADCOM. Laser-Cut Substrates for Microwave Tubes. Contract awarded to Northrop. A successful two-step high resolution etching process will be used to laser micromachine IBCFA anode circuit bed ceramic heat sink/mount/ insulator. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 5041, CORADCOM. Millimeter Wave Mixers and Arrays. Alpha Industry used computer controls to make MMW Schottky barrier mixer diodes that meet specs at 56, 94-120 GHZ, but not 140 GHZ. Impedence reduction of double ridged matching structures incorporated. Split block housing broached. For additional information, contact Al Feddeler, CORADCOM (201) 535-4062.

Project 5042, CORADCOM. Large Diameter Neodymium YAG Laser Crystal Boules. Litton Systems, Airtron Div., built a new station for growing larger 2 inch neodium doped YAG boules. Twelve rods were cut and tested and passed. Thirty rods may be used in GVS-5 rangefinder. Demo was held in March. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 1051, MICOM. Replacement **of Asbestos in Rocket Motor Insulations.** The effort will address replacement of asbestos in composite grain inhibitors and in smokeless, rubber base calendered, and calendered elastomeric motor insulators. Material selection and testing is in process. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5109, CORADCOM. Precision Low-cost Surface Acoustic Wave Delay Lines-UHF Appli. TRW is optimizing fabrication and test processes for 403 and 506 MHZ UHF surface acoustic wave devices. Four mask sets were built, each with transducer pairs. Test fixtures were designed and semiautomatic assembly equipment bought. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3010, CORADCOM. Millimeter-Wave Sources for 60, 94, and 140 GHZ. Hughes impact oscillators showed no effect when exposed to 10,000 RAD/SI. Pilot production of MMW impatts is completed. Modulator timing and pulseforming problems overcome. Resistor heating caused circuit to be unstable. Solution: mount external to can. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3011, CORADCOM. Indium-Phosphide gunn Devices. Varian Associates is mechanizing the thinned integral heat sink process to get 10 micrometer device structures. Metallization and alloying steps were combined. SEM inspection and package etching were eliminated. In-process measurements aid uniformity. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3026, CORADCOM. High Pressure Oxide IC Process. ET & D Labs ordered a major revision of the furnace to reduce convection of hot gas to cold vessel walls. Now in use is a closed bell-jar type container around the furnace elements. New parts were made and fitted into the chamber. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3031, CORADCOM. 10.6 μm Co-2 TEA Lasers. Raytheon established production methods for forming, sealing, and processing ceramic laser housings. Worked on electrodes and mirrors for alignment and parallelism. Optimized gas mixture. Need polarizing element in laser cavity and this led to cost growth. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3501, CORADCOM. Third Generation Photocathode on Fiber Optic Faceplate. ITT has had trouble growing gallium-arsenide layers on gallium-arsenide wafers to make 3rd generation photocathodes. ITT developed a multi-frequency scan test to check layer thickness. NV + EDL + ITT think they have the uniformity problem solved. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3505, CORADCOM. High Contrast CRT Phosphor Deposition and Sealing. Technical transfer from Lockheed to Hughes enabled Hughes to fabricate faceplates. The faceplate has a 3-fold increase in red luminance. Reproducibility of faceplates is high. Sputter target was achieved and is satisfactory. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 1018, MICOM. Improved Manufacturing Processes for Dry Tuned Accelerometers (CAM). This project is complete. An end of contract demonstration was held

March 29. The technical report is being prepared. Final testing is under way. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5002, TACOM. Fabricating Torsion Springs From High Strength Steels. Preliminary analysis of fatigue life shows E4350 steel is outperforming E4150. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 5005, TACOM. Computer Aided Design for Cold Forged Gears (Phase I). The data section of the computer program that handles both spar and helicar gear geometries has been completed. The drawing routines were modified. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 5014, TACOM. Foundry Casting Processes Using Fluid Flow and Thermal Analysis. University of Pittsburg was awarded a contract to expand the geometric capabilities of the current system. Presentations on the results have been made to weapon system designers and foundry representatives. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 6350-2616, AMMRC. Automated Software Aids for Testing Requirements. The demonstration/evaluation was performed and proved the functional characteristics of the tool. Delivery and training for the software requirements analyzer for the tool has been accomplished. Installation in Government facility is in progress. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5147, CORADCOM. High Resistivity Polycrystalline Silicon. Hemlock Semicon Corporation modified the trichlorosilane reactor for production of 72 MM diameter detector grade polysilicon. They made 330 kilograms of polysilicon. Vapo-phase purification system is in progress. This gives us a domestic source of polysilicon. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 6350-2200, AMMRC. Automatic Identification, Sizing, & Counting of Particulate Contamination. The system is operational and sample preparation problems have been solved. New software incorporating recently developed algorithms for more precise measurements which are more user friendly have been procured. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2205, AMMRC. Holographic Inspection of Rotary Forged Preforms. Phase I System is electronically and mechanically complete and meets the technical criteria. For final acceptance, a demonstration of the operational requirements and certain computer software was conducted in December, 1982. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2418, AMMRC. Half Life of Tritium Lamps. This project has been delayed due to the late receipt of hardware samples and test results. The data anlysis was not completed until January 1983. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2419, AMMRC. Fire Control Components Automatic Inspection. This project has been completed. The OTF criteria developed by this project cannot be recommended for resolution measurement for inspection of image quality of visual optical systems. This criteria can lead to false rejections of good optics. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2420, AMMRC. Optical and Dig Standards and Measuring System. NBS has completed the measuring equipment. A number of standards have been assessed. The results appear promising. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5010, CORADCOM. Bonded Grid Electron Gun. Varian completed computer analysis of the boron nitride electron gun bonded grid structure. Laser milling equipment was ordered. Techniques for production bonding the grid to the cathode are under evaluation. Guns will operate at less than 1000 volts. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 5000, CORADCOM. Production of Hot Forging of Alkali Halide Lenses. Highly successful processes for pressing IR lenses to shape have been developed by Honeywell. The water impermeable coating effort has not been successful, so implementation of the inexpensive KBR lens is not foreseen. Test method is very successful. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 6059, TACOM. Resin Molded Composite Materials. Fabrication of the trim vane is continuing. Quality assurance requirements are being formulated and a test plan has been submitted by the contractor for review. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 7925, ARRCOM. Bore Evacuator Boring. Planetary heads and gear case assemblies shipped to contractor's plant. Construction of special machine in process. Test com-

ponents also shipped to contractor. Projected delivery date of finished equipment was June, 1983. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7285, AVRADCOM. Cast Titanium Compressor Impellers. Tooling and patterns have been procured for the GMA500 second stage impeller. The impeller has been redesigned to avoid second and third order excitation frequencies at 102 percent design speed. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7807, ARRCOM. Programmed Optical Surfacing Equipment and Methodology (CAM). A contract was awarded to the University of Rochester for Phase II of this effort. Also, the twelve position tool changer is being used to load parts automatically and an interferometer is being built onto the bed of the machine to allow for testing. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 1076, MICOM. Automatic Recognition of Chips. Kulick & Soffa built prototype hardware for a semiautomatic chip recognition die bonding system visualized by R 79 3219 & R 80 3219. Spar robot, passive component feeders, video augmentation system, and chip tray pedestals are being evaluated. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1318, ARRADCOM. Production, Fill, Close and LAP in XM736 and BLU 80 Bomb. Fill and close drawings covering the track for weigh station and milling machine were completed. Optical and aluminum oxide moisture analyzers were evaluated. Inertia weld rework procedure was completed. Final status report received. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 0904, ARRADCOM. Chemical Remote Sensing Systems. The technical data package was analyzed. Contractors' facilities were visited to establish interferometer production processes. Cost estimates were determined for tooling and equipment for the interferometer pilot facility. Final status report received. For additional information, contact Donald Fischer, (201) 724-5957.

Project 1075, MICOM. Electronics Computer Aided Manufacturing (ECAM). Battelle drafted a master plan, wrote project descriptions, prepared a movie script, and finalized the architecture. Phase 1 final report was drafted. Project will fill technology voids and advance CAD/CAM/CAT of electronics items. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 7291, AVRADCOM. Titanium Powder Metal Compressor Impeller. Subcontractor has completed a complete redesign and fabrication of new fluid dies to make impellers. Consolidation source found inadequate. New source was found and consolidation was accomplished in 1982. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7802, ARRCOM. Establish Machine Tool Performance Specifications. The final technical report is being rewritten at the request of the project officer. A technical paper on machine tool specfications, based on the work associated with this prject, has been approved for presentation at NAMRC '83. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 6011, **TACOM. Springs From Fiber/Plastic Composites.** One rear spring assembly has been delivered to TACOM for lab testing. Dies have been designed and are being fabricated. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 7197, AVRADCOM. Fabrication of Integral Rotors by Joining. Inspection Specification and Material Property Data completed. Final status report received. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 1073, MICOM. Real Time Ultrasonic Imaging. The manipulator design is complete, and considerable progress has been made on alternate transducer development and the fabrication of the isometric image processor. In spite of milestone data shifts, progress is consistent with expenditures. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5024, TACOM. Gear Die Design and Manufacturing Utilizing Computer Technology (CAM). The script for the movie on the CAD/CAM of spiral level gears has been prepared with narration and suggested scenes. The contractor has proposed to forge in Phase III a large spiral level gear. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 7710, ARRCOM. Injection Molding of Rubber Obturator Pads. An ECP for implementing injection molding of 155 mm obturator pads at RIA has been approved. Revision of the appropriate drawing is in progress. Implementation will be initiated when the revision is completed. A final report has been completed. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7298, AVRADCOM. High Temperature Vacuum Carburizing. Phase 1, process development, is being continued. Setup of the Boeing-Vertol three gear roller and single tooth bending testers has been completed and will be operational when test specimens become available. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 7322, AVRADCOM. Low Cost Transpiration Cooled Combustor Liner. Work progressing on schedule for cleaning, surface prep, and etching and bonding tests for five materials—Inconel 617, Hastelloy X, HDA 230, Inconel 586, and Hastelloy C276. Low cost transpiration cooled combustor liner contract was awarded. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 1354, ARRADCOM. Sludge Volume Reduction and Disposal Process Study. Project activity completed. An interim technical report to be prepared will close out this project. Equipment purchase requests submitted to procurement office. RFBS issued and bid responses being evaluated. Layout and plan for sludge dewatering press and associated equipment is in preparation to provide contract design packaging for equipment installation. Determination made to dispose of dewatered sludge in a State approved chemical landfill. Funds were budgeted for equipment purchase and installation. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 5054, TACOM. Laser Surface Hardened Combat Vehicle Components. Heat treating and test evaluation of sample parts continue. Fixtures to hold the T-142 and T-156 end connectors have been designed and fabricated. CNC equipment will control the rotation of the components under the laser beam. Non-surface hardened end connectors and center guides have been purchased. Components are being heat treated. Lab evaluation of heat treated components is in progress. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 1086, MICOM. Cobalt Replacement in Maraging Steel Rocket Motor Components. Tasks one and two are under way and on schedule. This project is the second of a two phase effort. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 7948, ARRCOM. Establish Cutting Fluid Control System. Cutting fluid demonstration phase completed. Vendor survey of recycling equipment completed. Instructional briefings for production supervision held. Final technical report has been submitted and is being reviewed. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7340, AVRADCOM. Composite Main Rotor Blade. A contract for Phase 3 was issued. A safety-of-flight review, ground testing, flight testing, and root-end fatigue testing were completed. Flight testing resulted in excessive vibration at 80% of full flight envelope. Fatigue testing was successful. Final status report received. For additional information, contact Gerald Gorline, AVRADCOM (314) 263-1625.

Project 1088, MICOM. Optimized Mandrel Fabrication and Utilization for Composite Motor Cases. Structural requirements for both the Met(net) and inflatable reusable case mandrels determined from subscale testing. Design for Met full scale mandrel optimized. However, because of problems obtaining suitable materials, design of Met mandrel is continuing. Work is finished pending receipt of technical report from technical information division. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 4046, ARRADCOM. Quantitative Analysis of Blended Explosive Samples. Plan developed to investigate several parameters using polarographs at ARRADCOM and Lone Star AAP. Consideration given to mercury drop size, sample temperature, pipet accuracy, and deoxygenation. Remaining effort will now take place at Lone Star AAP. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 5068, TACOM. New Anti-Corrosive Materials and Techniques (Phase II). Three galvanized, unitized M151A2 vehicle bodies were fabricated using current production tooling and were electrocoated with epoxy primer. Two of these currently are undergoing road tests to determine corrosion resistance and structural integrity. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 7963, ARRCOM. Group Technology for Fire Control Parts and Assemblies. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7341, AVRADCOM. Structural Composites Fabrication Guide. Data gathering is continuing. A demonstration of composite structure fabrication techniques was presented at AVRADCOM. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 5075, TACOM. Military Elastomers for Track Vehicles (Phase II). T-152 track pads have been made and tested. T-142 track pads also have been manufactured and are being tested. Procurement actions and testing arrangements are being made for the T-156 (Abrams M1) track pads. Track rubber spec will be written. T-142 track pads containing Kevlar fibers have been manufactured. Track rubber specification will be written to encompass improvements. Spin-offs for other elastomer items will be realized. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

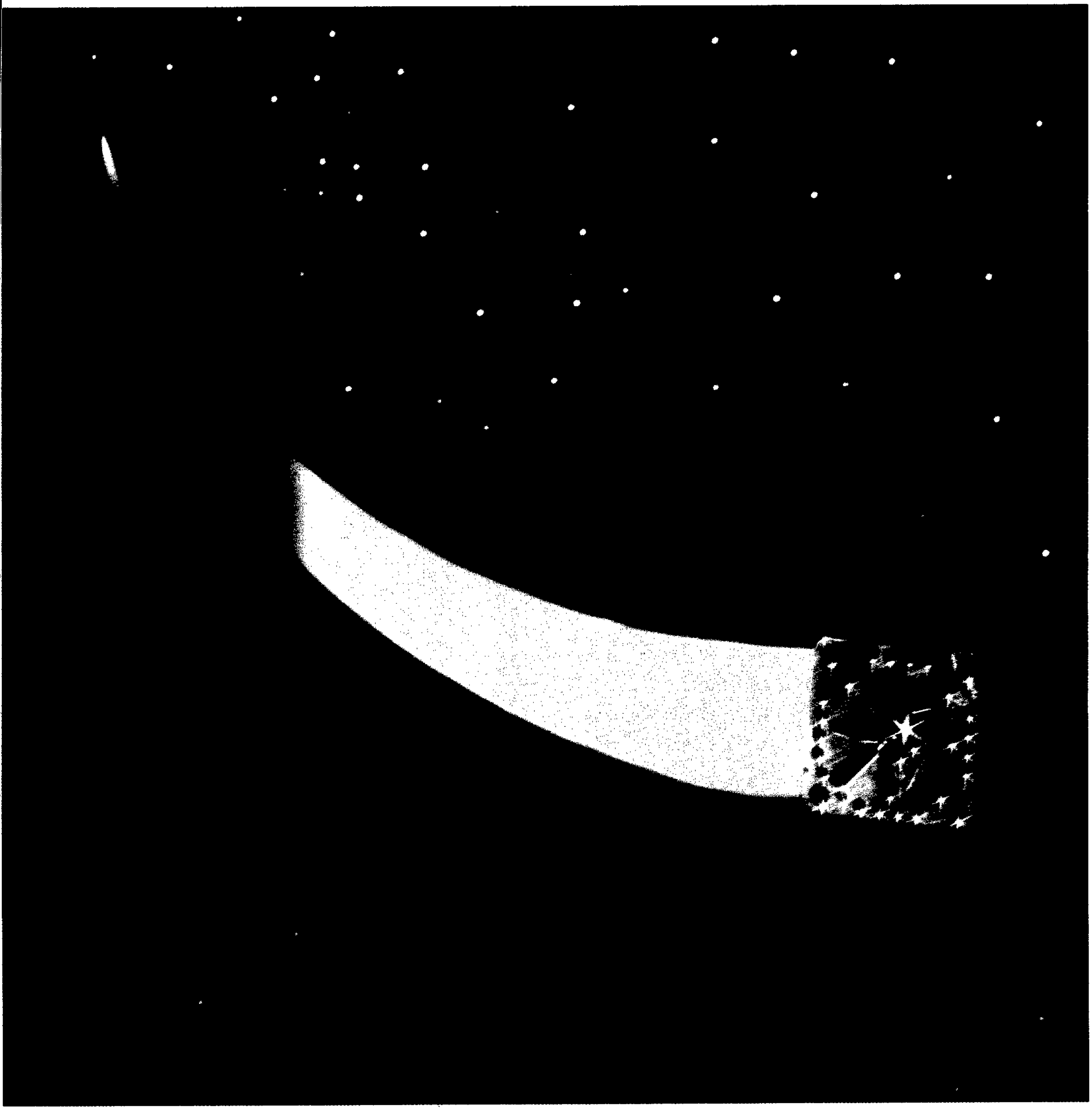
Project 4062 06, ARRADCOM. Prototype Production Tooling. The contract was awarded to Innova, Inc. Also, the prototype tooling design work will be interfaced to the recent tooling improvements made at EDS Corporation to insure proper incorporation into effort. For additional infloration, contact Donald Fischer, ARRADCOM, (201) 724-5957.

US Army

ManTech Journal

1984: A Year of Change

Volume 8/Number 4/1983



US Army
ManTech Journal

Volume 8/Number 4/1983

Contents

About the Cover

Significant new applications for an existing technology are under way in fluidics—one highly important one being the accurate temperature monitoring of molten steel during smelting and casting. Precise temperature sensing over several hours will enable engineers to cut fuel requirements/costs drastically. Invented by Harry Diamond Laboratories scientists more than a decade ago, the seeming limitless potential of fluidics devices is depicted in this imaginative illustration of one of the components by Battelle photographer Ralph Goodrich.

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Comments by the Editor


RAYMOND L. FARROW

The 15th Annual Conference of the Department of Defense Manufacturing Technology Advisory Group in early November, 1983 was a solid success, marked by the largest attendance since the inception of this important meeting.

Hosted by the U.S. Army, the meeting exhibited strong support from high levels from within the government, including the Department of Commerce and Bureau of Standards in addition to the various agencies of the Department of Defense. Several new programs were featured at this meeting of which more will be reported at a later date. We have been told that the 1984 meeting, to be hosted by the U.S. Navy, will be held in Seattle next December. We hope to see as many attendees there as were present at Orlando in 1983.

This issue of the Army Mantech Journal features reports of some significant achievements in manufacturing technology. The first article outlines a new CAD/CAM technique that makes close tolerance forging of spiral bevel gears feasible, the process reducing materials requirements and machining costs while improving fatigue life of the gears by 30 percent. The work was done by Battelle for the Tank-Automotive Command.

A second article on development of low cost armor from cast steel is described in our second article of this issue (the previous issue carried an article describing a different approach to the task by another industrial firm). This particular project was carried out by Blaw-Knox concurrently with the previously reported project done by Rockwell. By so doing, the Tank-Automotive Command saved considerable development time and the new capability was brought near production much earlier than if the projects had been conducted in sequence.

As is often the case with Army mantech projects, entirely new techniques are found not to be necessary in order to develop a feasible new production capability. Such was the result of a project by Waterbury Farrell Textron for the Army Armament Research and Development Command, in which a radical departure from current cup forming techniques was found unnecessary in forming two and three draw cartridge cases. The project determined that only sound current tool engineering principles need be applied to refine the current techniques in order to produce quality components.

A Texas Instruments project for the Army Electronics R&D Command likewise utilized existing electron beam direct writing equipment to develop a new manufacturing capability for standard bipolar circuits of conventional design. This was in sharp contrast with many published current investigations that seek to demonstrate improved per-

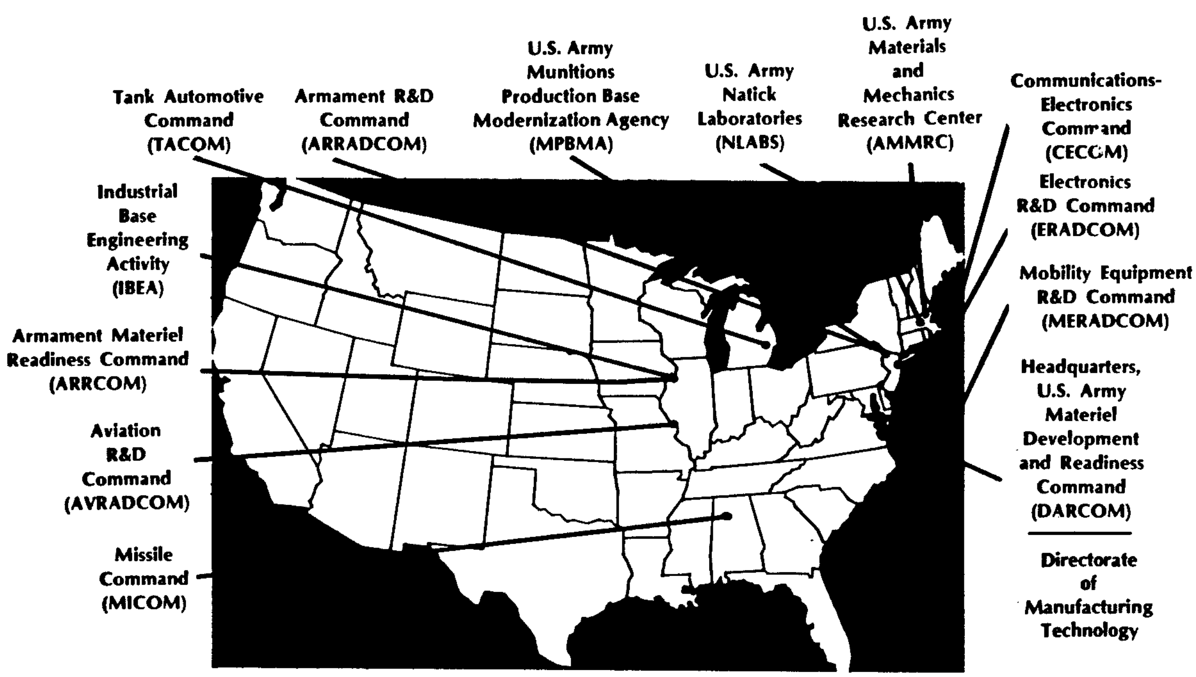
formance and packing density in these devices. The results of the Army project provide a significant step toward implementation of e-beam technology in VLSI circuit fabrication.

In the course of other mantech development programs, it sometimes is determined that the approach being pursued, though feasible, may be too costly to warrant further work. Such was the case with a project by Diffracto, Ltd. for ARRADCOM's Tank Infantry Systems Division. Basing their work on findings of a feasibility study by General Electric, Diffracto successfully demonstrated a technique for optically inspecting the gaps between component assemblies on the M456 projectile. However, during the cost analysis of project results, it became apparent the technique would be too costly for practical production, so the project was terminated. However, project results will be available for others conducting similar investigations at a later date.

Flexible manufacturing systems are causing great excitement in the manufacturing technology field, and the U.S. Army has joined those following this new thrust by developing such a system for the production of its Bradley Fighting Vehicle. In a project by FMC Corporation for the Tank-Automotive Command, a well planned, thorough program resulted in the evolution of a system configuration based on changing production requirements and system expansion factors. Group technology developed for this system has made possible new levels of production efficiency.

As has become our custom, this issue of the Army ManTech Journal also features a large number of brief reports on the status of ongoing projects. These briefs complete our summary of Army activities for 1983, with future issues to carry updates of these same (and also, new) projects during 1984.

DARCOM Manufacturing Methods and Technology Community



CAD/CAM Technique Makes It Practical

Spiral Bevel Gears Precision Forged

by
Taylan Altan
P.S. Raghupathi
A. Badawy
(Battelle's Columbus Laboratories)

D. Ostberg
(U.S. Army Tank-Automotive Command)

Close tolerance forging of U.S. Army spiral bevel gears, requiring only a single finish machining operation (or none), now is feasible in production with the help of a newly developed CAD/CAM technique. This method of manufacture offers many advantages because it reduces material losses and machining costs while increasing the fatigue life of the gears by 30 percent.

A recent U.S. Army Tank-Automotive Command project conducted by Battelle's Columbus Laboratories successfully developed the methodology of CAD/CAM procedures for manufacturing dies (via EDM) for forging spiral bevel gears. Further, it demonstrated that precision forging of spiral bevel gears is a practical production technique. Although no detailed economic evaluation was made in this study, it is expected that precision forging offers an attractive alternative to the costly gear cutting operations for producing spiral bevel gears.

CAD and CAM Integrated

In industrial practice, attempts are continuously made to introduce improved manufacturing methods to reduce production and life cycle costs. Close tolerance forging of spiral bevel gears—requiring only a single or no finish machining operation—offers considerable advantage over machining because this method of manufacture (1) reduces material losses and machining costs and (2) increases the fatigue life of gears up to 30 percent.

A few companies around the world are able to produce spiral bevel gears by precision forging. However, the development of the process for each new gear design requires considerable trial and error. Thus, application of computer techniques to the design and manufacture (CAD/CAM) of the gear forging dies represents an attractive alternative. Therefore, in this program, methods were developed to apply existing advanced computer aided design and manufacturing (CAD/CAM) technology (finite element, metal forming, and heat transfer analysis) to gear forging die design and manufacture. Gear forging dies were designed and manufactured according to the data supplied by the output of the CAD procedure; thus, the CAD and CAM processes were integrated. The results of the CAD/CAM techniques were evaluated for a given spiral bevel gear/pinion set by designing and manufacturing the forging dies via CAD/CAM.

In recent years, Computer Aided Design and Manufacturing (CAD/CAM) techniques have been applied to die design and manufacture for forging rib-web type aircraft structural parts, track shoes for military vehicles, and precision turbine and compressor blades. The experience gained in all these applications indicates that a certain overall methodology is necessary for CAD/CAM of dies for precision and/or near net shape forging. This approach indicates that the necessary inputs to the CAD/CAM system are: geometric description of the forging, data on billet material under forging conditions (billet and die temperatures and rate and amount of deformation), friction coefficient to quantify the friction shear stress at material and die interface, and forging conditions (i.e., temperatures, deformation rates, die lubricants, method of heating the billets, and suggested number of forging operations).

With these input data, a preliminary design of the finish forging die can be made. Next, stresses necessary to finish forge the part and temperatures in the forging and the dies are calculated. The temperature calculations take into account the heat generated due to deformation and friction and the heat transfer during the contact between the hot forging and the cooler dies. Thus, the elastic die deflections due to temperatures and stresses can be estimated and used to predict the small corrections necessary on

NOTE: This manufacturing technology project that was conducted by Battelle's Columbus Laboratories was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The TACOM Point of Contact for more information is David Pyrce, (313) 574-6467.

the finish die geometry. The estimation of die geometry corrections is necessary for obtaining close tolerance forgings and for machining the finish dies to the exact dimensions.

The overall procedure described above has been applied to CAD/CAM of spiral bevel gears as Phase I of this project.

The second part of the project (Phase II) involved Computer Aided Manufacturing (CAM) of the forging dies (from rough billet) and demonstration of the effectiveness of CAD/CAM by forging 20 spiral bevel gear sets. Phase III—Application of CAD/CAM techniques to actual production of bevel gears (spiral or straight)—has not yet started.

Five Tasks Carried Out

Five separate tasks were carried out under Phase I of the work: preform design, tool design, manufacturing of forging dies, forging trials, and finishing and dimensional checking of forged gears.

One of the most important aspects of the forging process is the proper design of preforming (or blocking) operations. The following features were considered in the design of the preform of the spiral bevel gear considered in this project.

Assure Defect Free Metal Flow and Adequate Die Filling. Adequate metal distribution is necessary in the blocker design to avoid forging defects, such as cold shuts and folds. The preform was designed as a solid ring (no teeth) with the outer dimensions as close as possible to the outer dimensions of the finished gear. This minimizes the amount of material to be moved during forging, and this in turn enhances die filling.

Minimize the Material Lost in the Flash. In steel forgings, approximately half of the cost of forging consists of material costs. On the average, 30 percent of the incoming forging stock is lost in the form of flash. Thus, approximately 15 percent of the forging costs are in the flash material of relatively little recoverable scrap value. The design of the blocker of the gear produced no flash. That was due to the fact that the volume (or weight) of the preform was slightly larger than the volume of the finish gear and that the proper material distribution throughout the preform volume was achieved.

Centering of Preform in Die. The preform was designed as a pancake with its center lying exactly on the center of the die. This was thought to insure even filling of the die cavity.

With the above considerations, an initial preform design was developed as shown in Figure 1. Figure 2 shows the preform positioned in the die. Later, another preform was designed and used in the forging trials, as discussed later. The new design shown in Figure 3 was wider so that the metal would not have to move very far to fill the cavity. The size of the corner radii was also reduced to provide more material at the corners. The billet material that was used for forging spiral bevel gears was cut from bar stock. The billet was upset to form a pancake having the proper diameter. The pancake was subsequently machined to the dimensions specified for the preforms.

Tool Design

The forge tooling was designed by using the results of Phase I of this project. The die assembly is a two piece design. The die insert, with the teeth, is one piece with a die ring around the insert to form the outer diameter of the

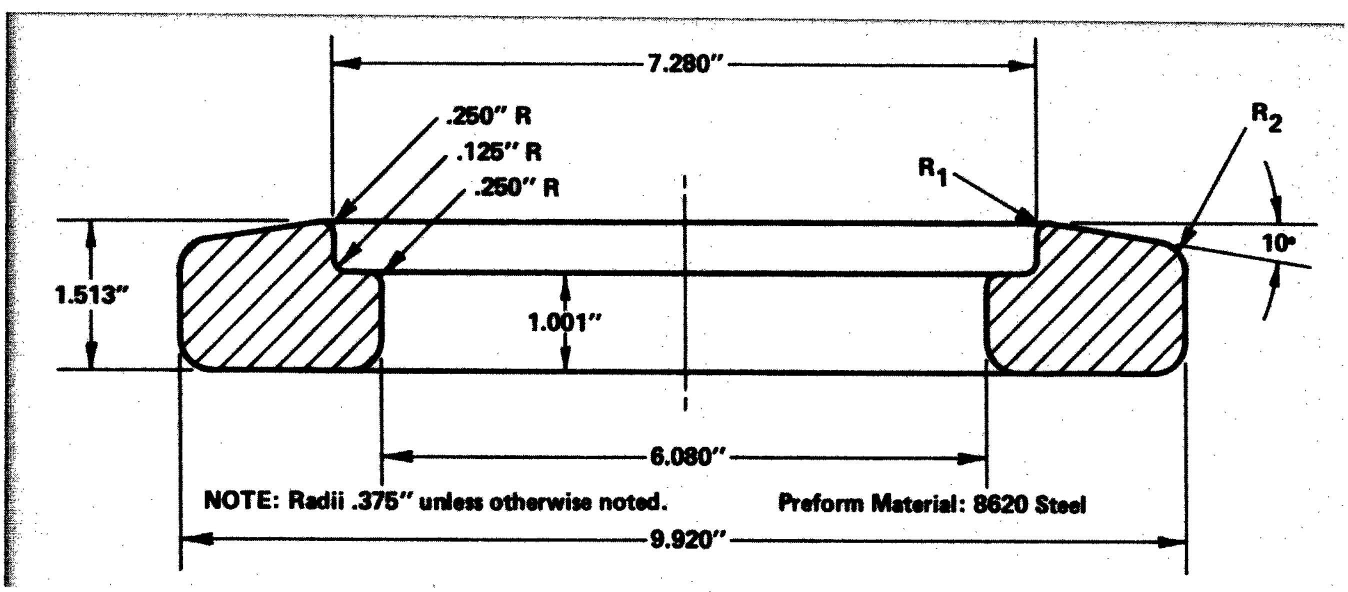


Figure 1

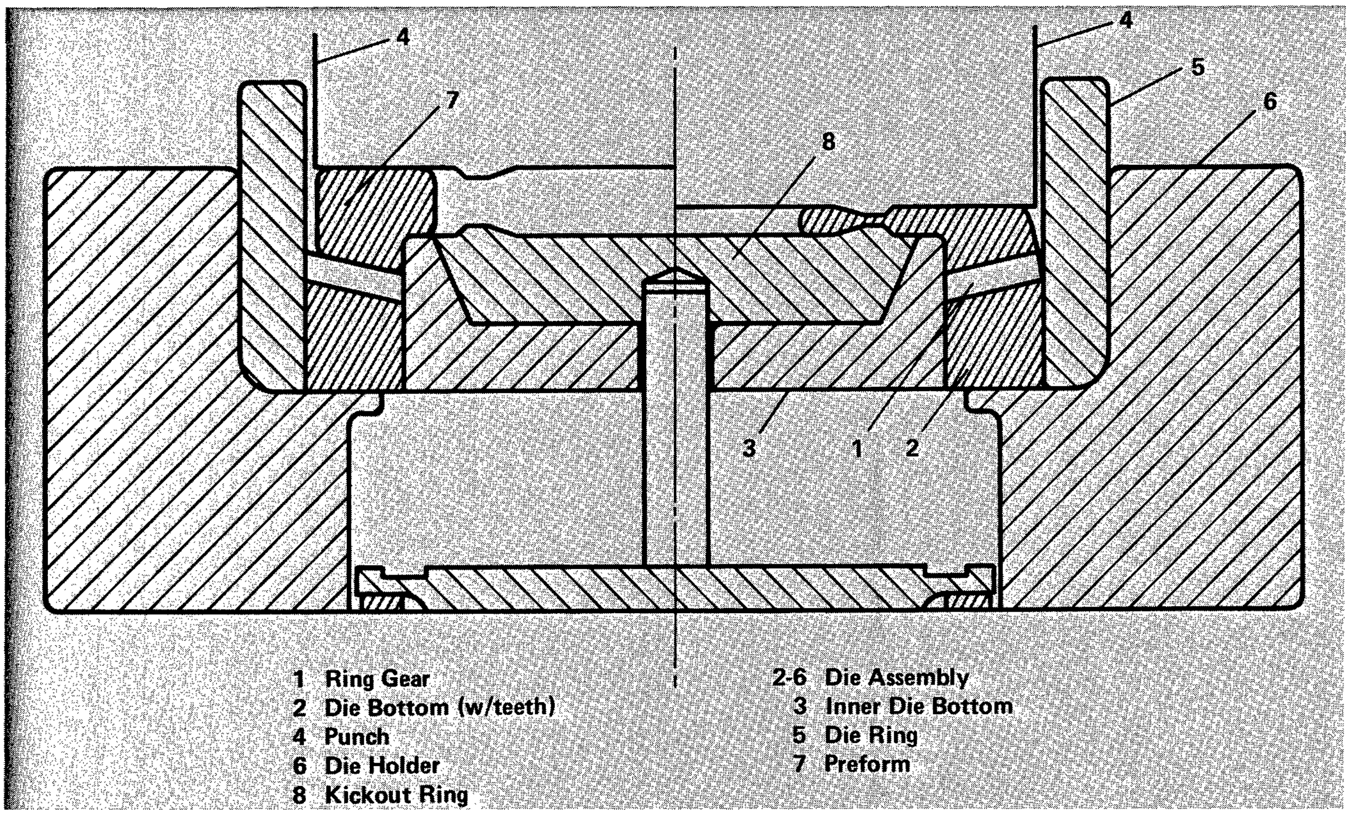


Figure 2

forging. At the center of the die is the die insert and the center kickout. The insert forms the inner diameter of the forging while the kickout removes the gear from the die after forging. The kickout is designed to lift the part by pushing on the center flange of the gear. It is activated by a mechanical kickout mechanism of the forge press which raises during the upstroke of the press. The kickout is also designed to contact the preform in such a way as to minimize the amount of material that is moved across the face of the insert. Figure 2 shows the kickout system.

The tooling assembly is shown in Figure 4. Incorporated in the forging design is the straight sided outer diameter with the provision of flashing toward the inner diameter. The inner diameter allows a 3/8 inch flash thickness on each side to trap the material. Inside the flash land is a gutter for excessive material to flow.

The punch holder design is different from the die holder in that it has a solid punch without any kickout. The punch also has provisions for placing spacers or shims between the punch and punch holder to vary the forging and flash thickness. This is necessary because it was decided to conduct the forging trials on a press which has a fixed bolster with no wedge adjustment. The shims help to adjust the forging thickness and the die fill within certain limits. The components of the die tooling setup are shown in Figure 4. The assembled tooling is shown in Figures 5 and 6.

Manufacture of Forging Dies

Precision manufacture of forging dies plays an important role in the success of precision forging of spiral bevel gears. The use of sound die manufacturing methods is essential if the required gear precision is to be achieved.

Based on the results of Phase I of this project, it was decided to use the hot work steel H-11 as a die material for the near net gear forging trials and the hot work steel H-13 as a die material for the net gear forging trials. The billet material used in both trials was 8620 steel. The die blanks were heat treated and then machined prior to the EDM of tooth cavities. The EDM electrodes were machined on a conventional gear cutting machine, using machine settings supplied by the CAD Computer Program SPBEVL of Phase I.

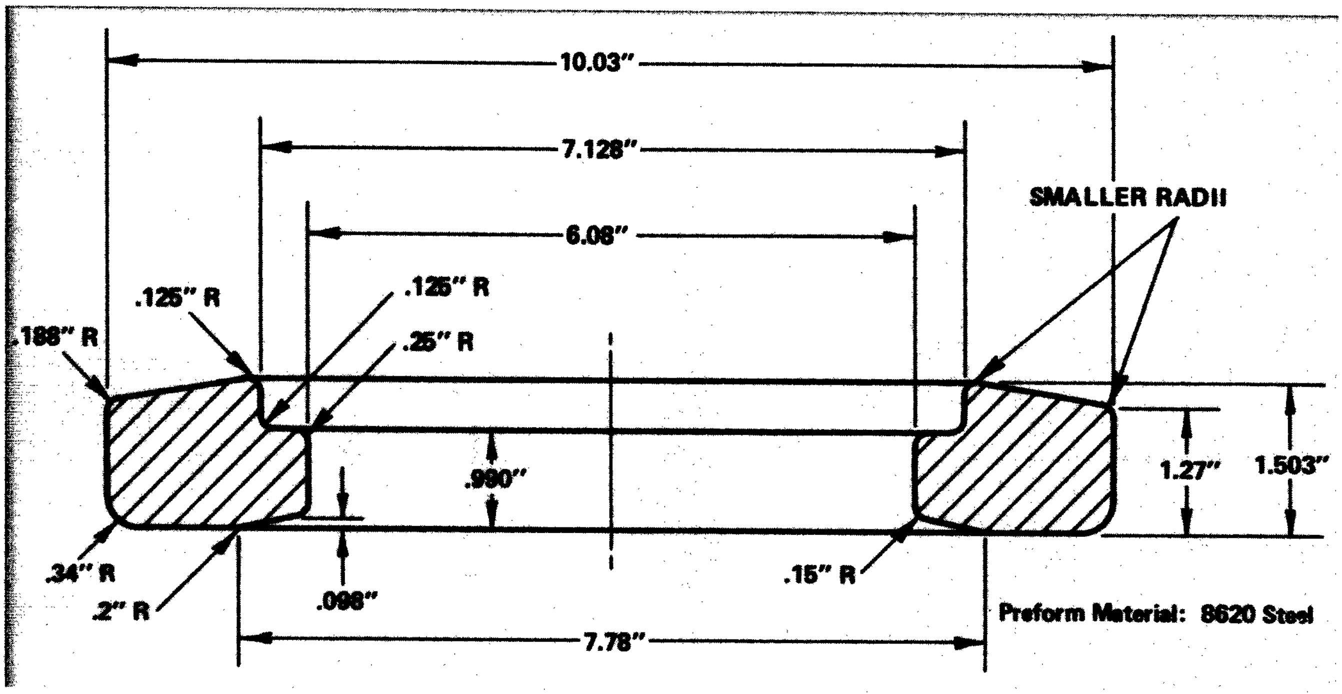


Figure 3

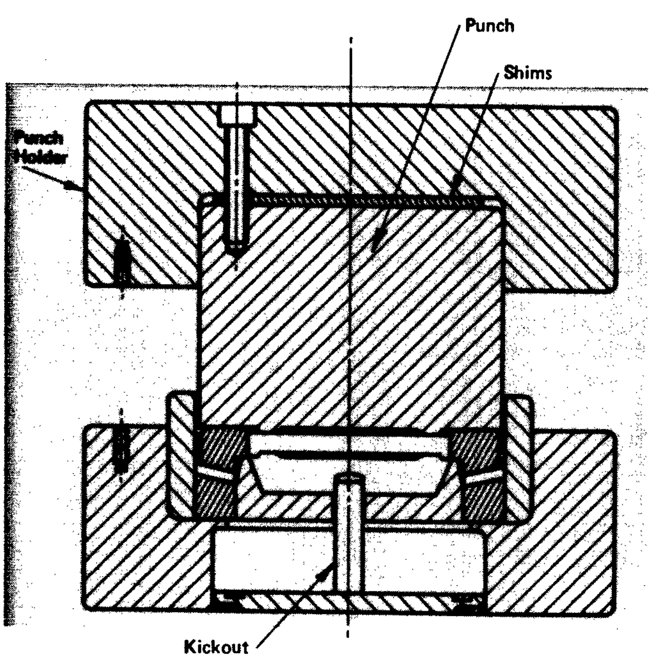


Figure 4

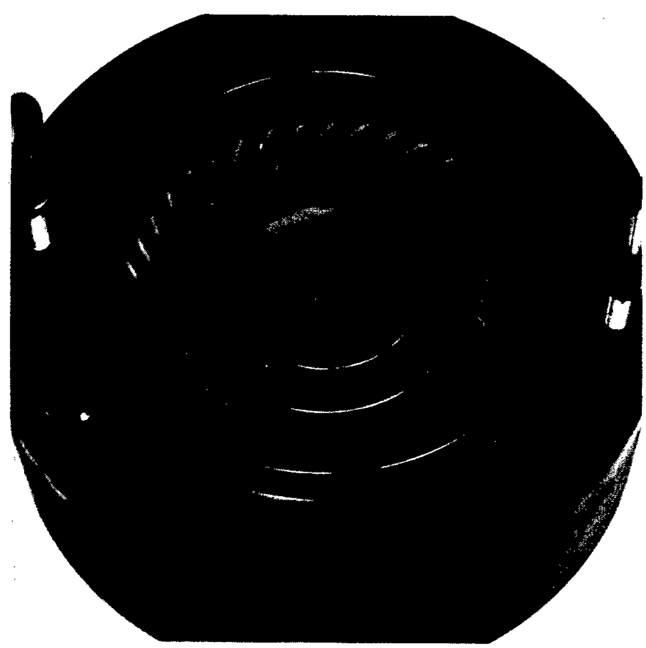


Figure 5

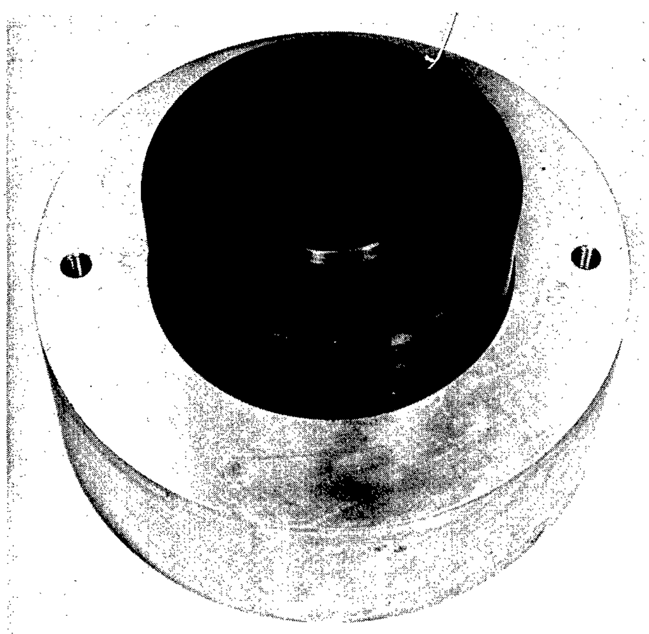


Figure 6

The electrode geometry accommodated all the corrections (elastic deflection due to loading, temperature differentials, and bulk shrinkage), as described earlier. The gear impression on the die was obtained by EDM. The EDM operation was performed using six electrodes in sequence. Each subsequent electrode was burned deeper until the required depth was obtained. Important steps in the manufacture of the forging dies included preparation of the electrode, EDM burning of the die, and the final grinding of the die after EDM.

It is worth mentioning here that this task (Manufacture of Forging Dies) makes use of all the data supplied from the Phase I part of this project; hence, integration of the Computer Aided Design (CAD) with the Computer Aided Manufacturing (CAM) was achieved in the production of forged spiral bevel gears.

Forging Trials

After manufacturing the dies with the required precision as described earlier, the gear forging trials were conducted at Eaton Corporation's Forging Division in Marion, Ohio. A 3,000 ton mechanical forging press manufactured by National Machinery Company, Tiffin, Ohio, was used to perform the trials. The press was selected based upon the anticipated forging load of about 2,500 tons and the space available for the tooling.

Three series of forging trials were conducted. During the first series, the technological details of the forging procedure such as heating, lubrication, part transfer, and cooling were established. During the second series of trials, 20 gears were produced with gear teeth forged to near net dimensions. These gears subsequently were machined with a single machining operation. In the third series of trials, 20 spiral bevel gears were forged with net teeth dimensions. Thus, the gear-pinion sets were obtained by machining only the back side of the forged gears and by machining the matching pinions.

The forging loads were monitored using load transducers attached to the frame of the press. These strain gage devices sense the strain in the frame of the press during forging and generate an electrical signal that is proportional to the load. Once the transducer system has been calibrated, the electrical signal can be read directly as load on the digital readout device. The system used was a Model LG-II designed and built by Helms Instrument Company.

The die lubrication used during the forging trials consisted primarily of a water base graphite material sprayed with pressurized air. A hand wand was used to direct the lubricant onto the die. Several billets were coated with a graphite based coated material to reduce oxidation during heating and improve lubrication during forging. However, no advantage was noted in surface finish, die fill, or forging load. The practice was discontinued after the initially coated billets were used.

After forging, the gears were placed, teeth down, in a sand-graphite mixture to reduce oxidation of the teeth during cooling. The back surfaces of the gears were still exposed to air so that the cooling rate would not be excessively slow.

Results of Forging Trials

During the first set of trials, a gas furnace was used to heat the preforms. This resulted in excessive scale formation and poor surface finish of the forged gear teeth. The heating was done by induction in the subsequent trials. The outside diameter of the preforms was considerably smaller than the internal diameter of the die cavity. As a result, some preforms could not be centered accurately and the forged teeth configurations were not uniform.

The second set of trials was considered very successful for the following reasons. First, the forged gear was uniform. All teeth looked almost alike. This meant that the centering problem encountered during the first forging trials was eliminated. Second, the surface quality of the

forged gear teeth was excellent. The induction heating of the preforms produced forgings with minimal scale. That meant that the scale problems encountered during the first forging trials—where a gas furnace was used to heat the billets—were eliminated.

However, two problems were encountered during the second series of forging trials: (1) There was incomplete filling at the toe and heel of the tooth. This problem was due mainly to the preform design. The radii at the outer and inner part of the ring are generous; consequently, there was not enough material at these parts to completely fill the die cavity. (2) Non-uniform temperature of the billet was noticed due to the change in colors in the inner part of the ring (cooler) and the outer part of the ring (hotter, i.e., the red color was brighter). This problem could be solved later by trying different heating cycles and times and lower induction frequency to obtain a uniform preform temperature.

The net forging trials (third set) were successful in producing gears with excellent surface quality and with superior die fill, as compared to near net forging trials. The new preform design used in this trial was the main reaons for the better fill in the toe and heel of the gear. As shown in Figure 3, the preform has a smaller radii in the toe and heel of the gear, compared with the near net preform. This additional material in the toe and heel enhanced the filling of those parts.

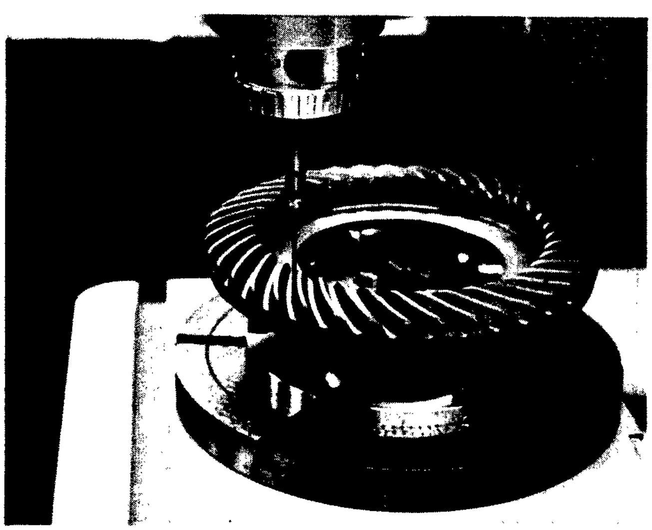


Figure 7

Dimensional Checking of Forged Gears

The forged gears were checked for dimensional accuracy on the Zeiss machine. The Zeiss machine is a computer controlled coordinate measuring machine (manufactured by Zeiss Corporation in West Germany) which produces plots of the tooth form variation as compared to the tooth surface of the cut master gear, produced by conventional cutting on a Gleason generator.

Figure 7 shows one of the forged gears being measured on the Zeiss machine. The plots show the relative deviation of the forged tooth profile as compared to a "master gear" tooth produced by conventional cutting (using a Gleason generator). Note that the relative error at the center of the profile is zero; i.e., the variations were measured relative to the center of the coast and drive surface of the master gear. The maximum variation was 0.003 inch (0.0762 mm). This difference can be compensated for easily in the cutting of the matching pinion.

Economics Attractive

The main goal of this program is to demonstrate that the close tolerance forging process—combined with CAD/CAM— is an attractive and economical method for manufacturing spiral bevel gears. To achieve this goal, the use of advanced CAD/CAM techniques to design and manufacture the forging dies was necessary. The project was successful in that it

- Developed the details of CAD/CAM for making the forging dies
- Forged gears with near net and net teeth surfaces
- Demonstrated the practicality and economics of precision forging spiral bevel gears.

It is expected that the techniques demonstrated by this project can be used for manufacturing spiral bevel gears (on a production basis) by forging. The matching pinions are to be manufactured conventionally by gear cutting. Thus, by eliminating the tooth cutting process for the gears, which represents the costliest operation in producing matching gear-pinion sets, considerable savings in manufacturing costs can be expected. In addition, existing data on forged bevel gears illustrate that forged gears are superior—in terms of fatigue life and load carrying capability—to cut gears. Consequently, a similar improvement in performance can also be expected from forged spiral bevel gears.

Improved Ballistic Properties

Low Cost Armor From Cast Steel

DONALD E. PHELPS is a Senior Project Engineer at the U.S. Army Tank Automotive Research and Development Command (TARADCOM). He holds a B.S. in Chemical Engineering from Tri State College, Angola, Indiana. Mr. Phelps has been associated with various activities related to armor and its fabrication since 1952. He currently is a Materials Engineer in the Armor Application Function of the Combat Systems Division, Tank Automotive Systems Laboratory, TARADCOM.

Concurrent mantech programs with two different suppliers helped the U.S. Army Tank Automotive Command achieve its objective of reducing costs and weight of armored heavy vehicles through the use of cast components. Considerable development time was saved and the new capability was brought near production earlier than would normally have been the case. The objective of both investigations was to determine how cast armor could be produced which would approach the ballistic performance of rolled welded armor.

In an article in the most recent issue of the U.S. Army ManTech Journal (Vol. 8, No. 3), the efforts of Rockwell International were described. The Rockwell approach concentrated on examining additives to the metal, special chills, controlled solidification, improved feeding, location and size of gates and risers, and special heat treatment.

This article describes the work of Blaw-Knox Foundry & Mill Machinery, in which they emphasized casting soundness through riser and chill design and sulphur content control—via selection of metal scrap used and also melt practices followed. Their specific objectives were as follows:

First, develop a technology capable of producing improved ballistic performance in cast armor products. Then, achieve a production practice that will assure a 4 round V50 Protection Ballistic Limit significantly higher than specification requirements for 5 inch thick cast plate and approaching the ballistic capability of rolled armor. Such were the objectives of recent work completed by Blaw-Knox Foundry & Mill Machinery for the U.S. Army Tank Automotive Command. This investigation covered the casting of plates and shapes to determine if improved ballistic protection can be provided by cast armor. The main considerations in the development were casting soundness through riser and chill design and sulphur control by scrap selection and melt practices.

Casting Practices

All test plates and simulated turret sections were molded using conventional no-bake binder/silica sand system with a chromite sand facing. A water base zircon sand wash was applied to all mold surfaces. The gating and risering practice for the flat test plates is shown in Figure 1. The drag side chill for promoting directional solidification was used in four of the test plates. A total of 14 plates 48 in. by 60 in by 5 in. were provided for test purposes.

NOTE: This manufacturing technology project that was conducted by Battelle's Columbus Laboratories was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Directorate for manufacturing Technology, DARCOM. The TACOM Point of Contact for more information is Donald E. Phelps, (313) 574-6433.

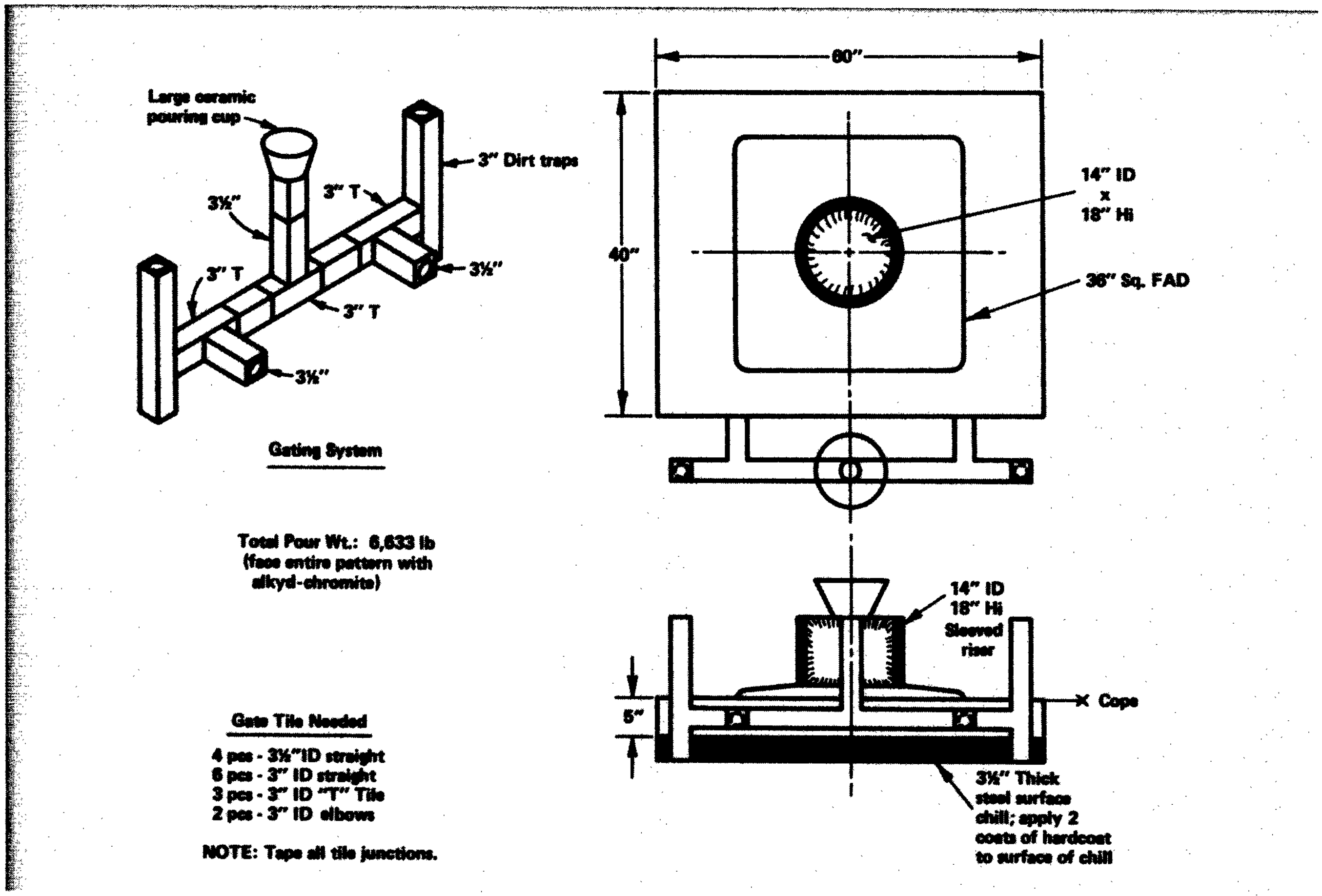


Figure 1

The gating and risering practice for the simulated turret sections is shown in Figure 2. Three sections containing variable thicknesses up to 5 in. were provided for test purposes.

Sulfur Control the Key

The control of sulfur in the melt, which was a primary objective in the manufacture of the test material, was accomplished mainly through scrap selection and slagging off after meltdown. One heat was made using a proprietary desulfurizing compound injected into the steel in the ladle. This compound and the associated injection technology was supplied by Reactive Metals and Alloys Corporation. The results of using this technique were particularly impressive; the sulfur was reduced from 0.015 to 0.009 percent.

The petro-carb injector was modified for injection purposes. DEOXSULF-8M (92 percent lime plus 8 percent magnesium powder) was then injected into molten steel in ladle. DEOXSULF-25 was added in the ladle to form basic slag with high V-ratio. A fabricated portable lance holder was used to hold high alumina refractory lance. Liquid argon with a vaporizer was used as a source of argon gas in this set up.

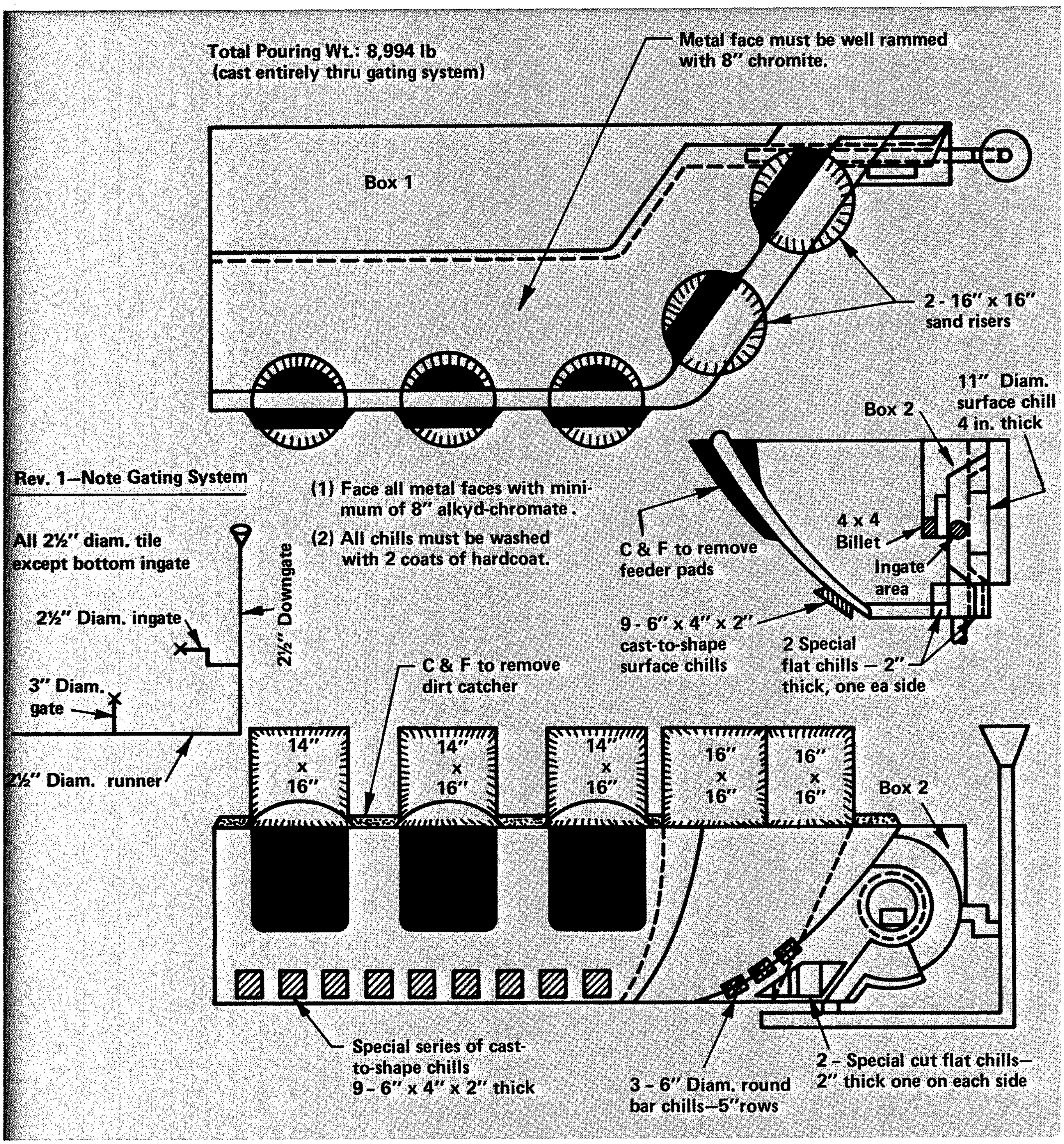
The heat (50,000 lbs) was worked in a second electric furnace to low phosphorus and .015 inch sulfur level. In addition to DEOXFULF-25 (500 lb), ladle additions of Ferro-Silicon (150 lb) and Hypercal (175 lb) were made for deoxidation per melt practice. Argon gas injection was started just before furnace tap. Tapping was completed in 3 minutes, then DEOXSULF-8M was injected using argon as carrier gas for 2 minutes.

Several observations were made. There was an effective stirring of steel in ladel. A minimum freeboard of 30 inches was required to avoid any spillage of molten steel. No significant emission of smoke was noted.

Ladle temperature was 2880 F (tap temperature 2920 F). However, an additional temperature drop of about 50 F was expected on account of injection.

Analysis of the ladle slag showed that the oxides of calcium, silicon, iron, magnesium, manganese, and chromium were 50.4, 26.7, 2.22, 9.0, 3.7, and 0.25 percent, respectively. Ferrosilicon and Hypercal were added in ladle for deoxidation, which increased silicon dioxide content in slag. Iron oxide content was significantly low, which helped desulfurization.

Final analysis of the armor heat showed the following percents: carbon 0.3, manganese 1.22, silicon 0.32, sulfur 0.009, phosphorus 0.014, chromium 1.10, nickel 1.43, and



Total Pouring Wt.: 8,994 lb
(cast entirely thru gating system)
Metal face must be well rammed with 8" chromite.
Box 1
2 - 16" x 16" sand risers
11" Diam. surface chill 4 in. thick
Box 2
Rev. 1—Note Gating System
(1) Face all metal faces with minimum of 8" alkyd-chromate.
(2) All chills must be washed with 2 coats of hardcoat.
C & F to remove feeder pads
4 x 4 Billet
Ingate area
All 2½" diam. tile except bottom ingate
2½" Downgate
2½" Diam. ingate
3" Diam. gate
2½" Diam. runner
C & F to remove dirt catcher
9 - 6" x 4" x 2" cast-to-shape surface chills
2 Special flat chills – 2" thick, one ea side
14" x 16"
14" x 16"
14" x 16"
16" x 16"
16" x 16"
Box 2
Special series of cast-to-shape chills
9 - 6" x 4" x 2" thick
3 - 6" Diam. round bar chills—5" rows
2 - Special cut flat chills— 2" thick one on each side

Figure 2

molybdenum 0.56. Analysis of dissolved gases in the steel showed .0162 percent oxygen, .0076 percent nitrogen, and .005 percent hydrogen for the pre-tap steel. For the final steel, oxygen was .0126, nitrogen .0092, and hydrogen .0005. Oxygen content was reduced by 20-25 percent. However, there appears to be some pickup of nitrogen, which is likely during tapping the heat and stirring of steel. Hydrogen remained unchanged.

Chill Experiments Dropped

Of the five test plates which were chilled in an attempt to improve total cross-section soundness, one had to be scrapped because of a hot tear on the chilled surface. Although initially the use of chills was one of the objectives in this program, subsequent ballistic firings showed a poorer performance in the chilled plates versus unchilled plates and this portion of the program was dropped with no further evaluation of the hot tearing.

The chill cast test plates were found to be erratic in Charpy results of the chilled and unchilled sides and to have lower ballistic limits on the average than unchilled test plates. These results are thought to be due to two factors: a shift in the thermal centerline and directional properties, both resulting from the chill practice. For this reason, the balance of the test plate program was carried out using unchilled test plates. These results are thought to be due to two factors: a shift in the thermal centerline and directional properties, both resulting from the chill practice. For this reasong, the balance of the test plate program was carried out using unchilled test plates.

Unchilled Plates Show Good Results

The test results on unchilled plates were very encouraging. The Charpy values were relatively uniform from cope to drag and the average ballistic limit of these plates was 339.3 fps above the acceptance ballistic limit of cast plate at 45 degrees obliquity. In addition, in a spaced array configuration at 30 degrees obliquity, ambient temperature and a 105 mm projectile, the average ballistic limit of three cast plates (3250 fps) was only 80 fps below the rolled steel (3330 fps) and the highest cast plate (3332 fps) equalled the rolled plate. For simulated turret sections, the spaced array test at 30 degrees obliquity and ambient temperature with a 105 mm projectile showed a higher ballistic limit than rolled steel tested under the same conditions (i.e., 3391 fps for cast versus 3330 for rolled steel). This indicates that in this configuration at least, cast armor can perform as well as rolled steel.

Recommended Practices

Wherever possible the casting design should incorporate tapered sections and radii corners of constant maximum thickness. Gross changes in section thickness should be blended and isolated heavy sections avoided. Based on the test data, the highest and most consistent results were obtained using a standard commercial casting practice. The riser system should be designed to take the maximum advantage of the casting design in promoting directional solidification. End effect chills may be used as required to aid directional solidification, but surface chills should not be used. Casting soundness should be of the highest possible level, limited only by casting design.

Within the range of sulfur analyses (0.009-0.019 percent) in this program, no significant difference in test results were observed. It is felt, however, that the sulfur should be maintained in this range (0.020 percent maximum) for consistent results.

The heats used in producing these test plates were deoxidized with ferrosilicon and Hypercal, a proprietary compound containing aluminum, calcium, silicon, and barium. This practice was used to promote a Type III sulfide morphology for consistent impact results. For heat treatment, the standard practice of water quench and temper is adequate to maintain the properties obtained in their product.

Cost Increases Minimal

A slight cost increase may be required if maximizing directional solidification and soundness requires the use of additional risers or a more complex mold assembly. The casting design is the major consideration governing cost considerations in this area. The sulfur limit of 0.020 percent can be maintained only through the use of (1) select scrap, (2) increased processing, or (3) the use of proprietary desulfurizing compounds. These steps would result in a minor cost increase. Because there is no change from standard practices for deoxidation and heat treatment, no increased cost would result.

Cast Armor Approaches Rolled

Based on the results obtained in this program, it is possible to produce cast armor shapes having ballistic protection capabilities approaching the performance of rolled armor with a minimum increase in cost. The main cost considerations would be in the areas of casting design (to complement riser practice) and sulphur control by scrap selection and/or melt practice.

Sound Tool Engineering, 1300 Cups Per Minute

Forming Of Two Draw Cartridge Case Cups

BOHDAN Z. HAJDUCZOK is a manager of programs for metal parts and load, assemble, and pack at the U.S. Army Munitions Production Base Modernization Agency, Dover, N.J. For the past five years he has been responsible for programs establishing production base facilities for mass production of small caliber ammunition. Previous engineering activities were related to fuze and artillery items, including design, development, testing, and production. He has been with the U.S. Army as a mechanical engineer since 1958, following several years of engineering work for industrial firms. He received his M.S. in Mechanical Engineering in 1961 from New Jersey Institute of Technology. A member of ASME, he has received numerous Individual Achievement Awards and has been nominated for Presidential Citation and Secretary of the Army awards.

Radical departure from current cup forming techniques was found unnecessary during a recent manufacturing technology project whose purpose was to impove ways of producing two and three draw cartridge case cups. The project results determined that, to achieve set goals of improvement, only sound tool engineering principles need be applied to refine the current technique so that quality components could be produced on a continuing basis.

Under a United States Army Armament Research and Development Command project, Waterbury Farrel developed a new cartridge case cupping technique which combines a highly efficient tool set design with a special double action press that accommodates this tool set envelope and its stroke requirements to fabricate both 5.56 mm and 7.62 mm 2 draw cups. The web scrap loss was not to exceed 37 percent. The proposed machine resulting from this study must also be of sufficient capacity to produce both 5.56 mm and 7.62 mm two draw cups.

Development of Cup Tooling Geometry

The primary task associated with this program was the evaluation of cup forming tool geometry. The test and evaluation of various tool configurations was performed in a single action, 45 ton, gap frame press. A commercial two post die set was used to contain the blanking, cupping and/or draw tooling.

The various punch loads were also monitored during these initial tests. This provided baseline data for the design of the multistation tool set.

The information derived from this test program also provided us with the indicators that dictated the final tool configuration to be utilized in multistation tooling. This approach in tool configuration development testing reduces the number of variables that must be tested and evaluated in multistation tooling.

The material utilized during this phase of the program was 1.25 inch wide x .138 plus or minus .002 inch thick and was the standard copper alloy No. 260 annealed to specification MIL-C-50. The physical and chemical properties were of normal values and no significant or unusual impurities were found. Chemical analysis should be copper-69.22 percent, iron-.037 percent, lead-.003 percent, tin-.007 percent, and the remainder zinc. The following elements were found to be less than 0.005 percent: phosphorus, arsenic, nickel, silicon, aluminum, manganese, cadmium, and antimony.

Tests were performed as single operations. Namely, separate blanking, first draw, second draw or a single combination cup and draw die mounted in a two post die set.

NOTE: This manufacturing technology project that was conducted by Waterbury Farrel was funded by the U.S. Army Armament Research and Development Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Bohdan Z. Hajduczok (201) 724-2712.

Tool Testing

The initial selection of a die design to be tested was of a standard approach universally accepted for cupping operations. The blanking die (Figure 1) diameter was .704 inch, while the blanking punch (Figure 2) was .700 inch. The cupping die had a nominal draw radius of .25 inch with a draw land of .12 inch. The second or lower die had a take-in angle of 10 degress (included) with a bend radius at the intersection with the .12 inch wide draw land.

Two draw cups produced with these tools exhibited good side wall variation control with a minimum base thickness reduction. These are the two principal characteristics that were looked at during the early testing phases.

The side wall variation for these cups at the .077 inch location was .0005 to .0015 inch T.I.R. The side wall variation at the .269 inch location was .0015 to .003 inch. The base thickness was .134-.135 inch.

The mouth edge of the cup had a positive taper—that is, high at the inside and lower at the outside diameter. The angle per side of this taper was approximately 19 degrees.

The attributes of this cup with respect to cup quality would be considered fair. Wall variation was beyond the desired limits and under the controlled test conditions we anticipated better results, but as base line data it produced encouraging results and provided the necessary steps to reach the next level of testing.

Peak load values obtained for the three operations were blanking-10,823 pounds, first draw-6,165 pounds, and second draw-7,000 pounds.

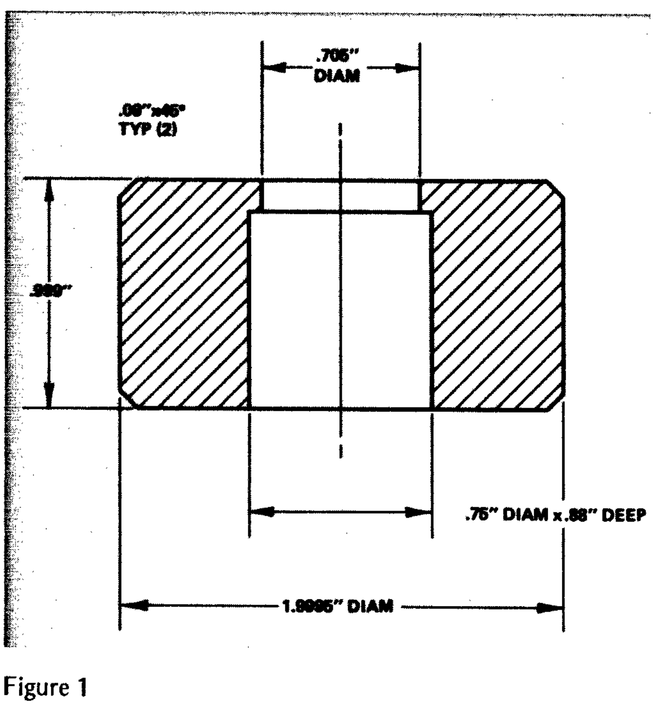


Figure 1

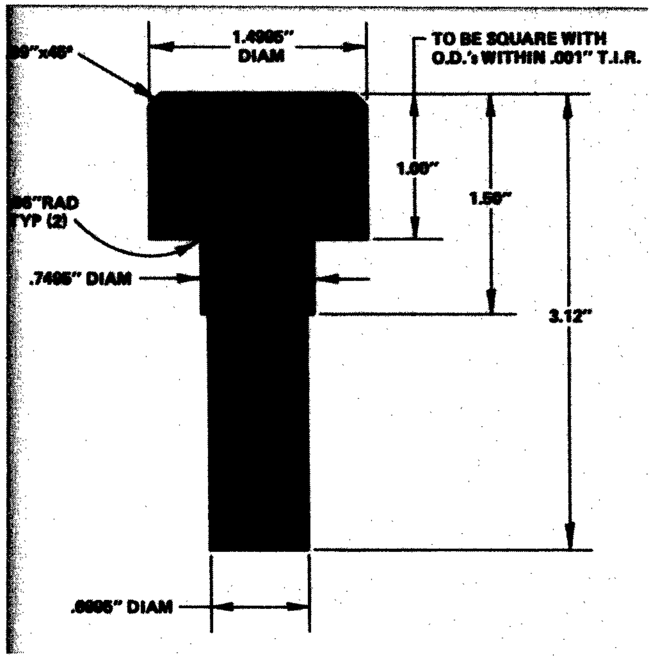


Figure 2

Single Die Design

A single die that provided the initial draw radius plus the take-in angle to the final draw land was tested next. The tool setup had the blanks confined in a set edge over the mouth of the die. The blank, as it was presented to the mouth of the die, had only circumferential line contact near the top of the .138 inch draw radius.

The cups produced with this die had uniform material distribution at the mouth. Side wall thickness variation was within control limits also. The exceptions were that, first, the cross-section of the mouth was cone shaped; this was not the desired mouth configuration. Second, the base thickness was .132 inch which is a .006 inch reduction for the input material. A base thinning of this magnitude under controlled test conditions is not desirable.

The peak load generated during the forming operation was 7,578 pounds. Noted of interest was a slight hesitation in load build-up as the blank reaches the point where the initial cup shape is developed and then the load drops off slightly before the cup starts to enter the final draw land portion of this die.

A secondary test made with this die was to produce cups from four different blank diameters. The blanking punches used has the following diameters: .700 inch, .696 inch, .692 inch, and .688 inch. The blanking die remained constant with a .704 inch inside diameter.

The cups produced with this one variable parameter did not exhibit dramatic variations in physical dimensions. The form of the cup mouth showed a slight variation in conformation but could be classified as not significant

within the boundaries of this test. The standard blanking punch die diameter relationship would remain at a differential of .004 inch on the diameter. This die configuration required modifications to determine if the cup mouth shape and the thin base characteristic could be improved.

The single die design was modified (Figures 3 and 4) so that the mouth diameter was decreased to a .670 inch diameter and the initial draw radius was increased to .1875 inch. The included angle of this die duplicated the original angle.

The evaluation was based on varying the die mouth configuration (diameter), the initial draw radius, and finally the included angle of this die.

The single die designs, plus modifications, did not produce good cups. The magnitude of the draw radius and the degree of take-in angle must generate an unstable blank draw punch relationship which results in poor quality cups. In addition, the base thickness of the cups was reduced to .130 inch, only 008 inch reduction from strip thickness.

Double Draw Die Design

The double draw die design (Figure 5) consists of two distinct dies. The upper, or cupping die, confines the blank within a concave radius configuration which is tangent to the first draw or cupping radius. The second draw or sizing die has a shallower included angle than previously tested dies.

Note that the cup produced in the upper die is completely clear of the .550 inch diameter draw land prior to any reductions being made by the lower die. This permits

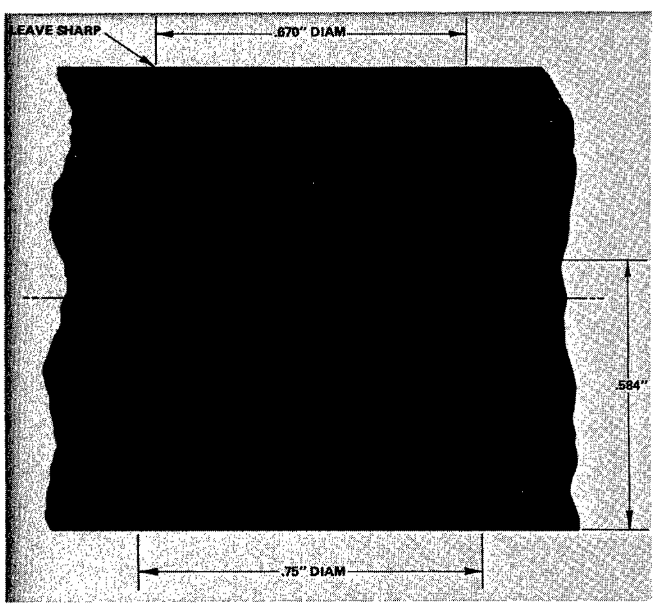


Figure 3

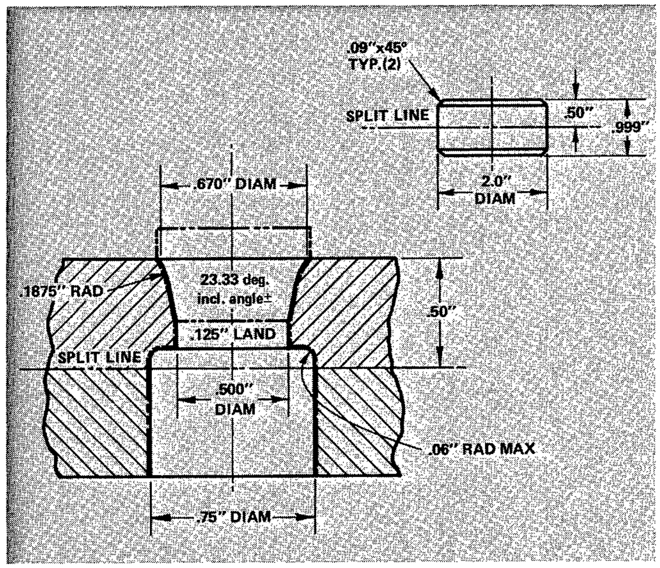


Figure 4

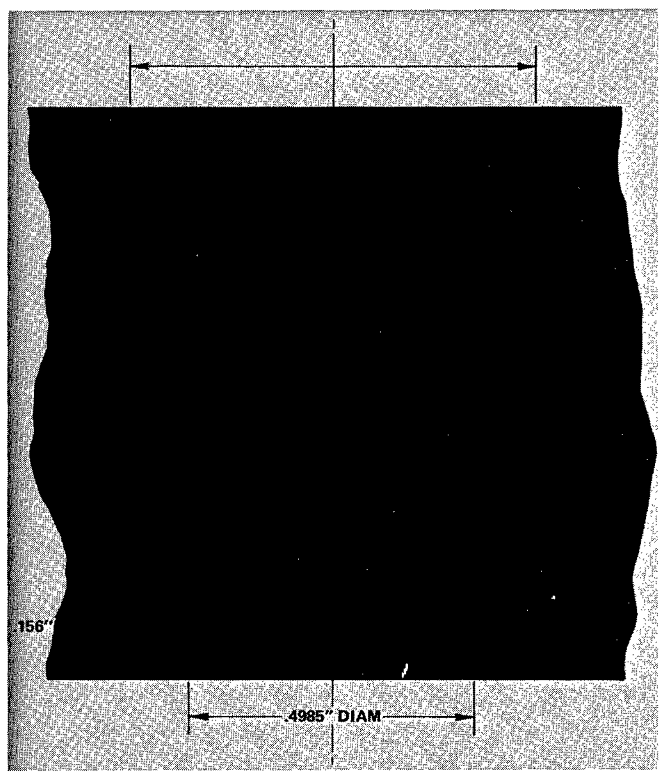


Figure 5

die coolant to be introduced between the dies as an assist to the final sizing operation. This philosophy can normally be applied to any multiple die drawing operation. Having two distinct dies generates a pattern whereby the machine loading diminishes to a zero value between the cupping and final sizing die.

The peak load values are 6,087 pounds for cupping and 4,565 pounds for sizing. In comparing these figures to the single die value, we find that the machine capacity requirement will be approximately 20 percent lower for the double draw die configuration, but the energy requirements are approximately the same.

Test results from this double draw die design produced cups which had the most desirable attributes, namely: the heaviest base thickness, minimum wall variation, and a tapered mouth cross-section (higher on the I.D. and lower towards the O.D.).

In the development of a desirable cup configuration with the double draw die design and in previous die designs, it was determined that the cup base thickness is a direct function of the initial deformation of the blank as it is pulled across the first draw radius by the cupping punch. The extension or thinning of the blank is never less than .004 inch. Earlier die design tests reached levels where the base thinning approached .013 inch.

The blank configuration does influence base thickness but to a minimal degree as evidenced in the above comparison charts. The average cup base thickness for the three types of blanks varied .0016 inch. The indented blank produced the thinnest cup base thickness, while the smallest diameter produced a cup with the heaviest base.

This appears to be a logical progression since the blank thinning phenomenon occurs during the initial contact between the draw punch and the die. The smallest diameter blank provides the least linear resistance as the transition from a flat blank to partial cup form is achieved.

There is a limit to this generalization. As we continue to decrease the blank diameter, the material thickness must be increased in order to maintain a specific cup weight. This blank geometry change, if great enough, would affect the drawability characteristics and alter cup quality.

The double draw die design also provided cups that had excellent wall variation characteristics. In fact, when three blank configurations were tested, they produced cups with a maximum wall variation of .0007 inch.

The results generated by this die design dictated the decision to use this design in our developmental 10-ton tool set.

Tool Quality vs. Cup Quality

During developmental testing, we noted that the dimensional accuracy of our tool components is very demanding. By laterally shifting blank "set edge" .006 inch, we produced lopsided cups which would be unacceptable on a production basis. The set edge in this case controls the blank to die concentricity. Our production design will have this set edge as part of the upper die, thus eliminating one interface dimension.

Also produced were cups using set edge with a zero clearance in relation to the draw dies. The O.D. to I.D. concentricity of this set edge was .0012 T.I.R. We were still able to predict where the height variations on a cup would be located by rotating this set edge. These were dimensionally acceptable cups that still exhibited small height variations. This type of testing indicates that the dimension control of production tooling will be very demanding if we are to maintain acceptable quality levels on two-draw cups.

With the die design evaluation completed, it became obvious that input strip thickness used during these tests was incorrect. The .138-.139 inch material produced cups with a .134 inch thick base. To satisfy requirements, strip material would have to increase to .142 plus or minus .002 inch. This shift would provide cups with a nominal base thickness of .137 inch.

Cup Forming Progression

To obtain a clearer visual picture of the forming technique and loads generated, a forming progression was developed. We incrementally formed a 2 draw cup and measured the loads generated at each position during the incremental slide motion of the press.

Of interest is the base thinning during the initial cupping operation and then the slight base thickening obtained in the lower sizing die. This phenomenon in the lower die can be attributed to the die geometry in conjunction with the ironing of the cup side wall.

Modifications to Press

The initial inspection of the Bliss press revealed some real shortcomings with regard to machine quality. These deficiencies necessitated our instituting a press refurbishing program. This program would minimize any possible problems being generated by a machine deficiency that would affect product quality during our study program.

The machine components that required corrective action were:

(1) Refitting of the main journal bearings to a normal running clearance. (This was a reduction in the running clearance of approximately 50 percent).
(2) Refitting of the pitman bearing to minimize its excessive running clearance.
(3) Refitting of the journal bearings for the blanking slide eccentrics.
(4) Rescraping of the blanking slide bearing surfaces and the associated gibbing to correct an uneven wear pattern and to again establish a normal running clearance.
(5) Scraping of the bed and slide to ensure that standard parallelism values were maintained.

(6) Replacing of the wrist pin bearing liners for the blanking slide.
(7) Installing of bronze liners on the inner draw slide as no corrective adjustments were included in the original design.

Further, the original mechanical clutch assembly was replaced with an air clutch and brake assembly. This requirement was two-fold: we wanted improved operator safety and the finite control of our slide stop position.

The new cupping technique also required that the roll feed timing be changed from an eccentrically driven motion to a cam motion with a reduced cycle time. The increased length of the working portion of the draw slide stroke required this modification. In conjunction with this modification we utilized only the "pull" roll feed assembly, as dual roll feeds for this operation were not deemed necessary.

The increased strip width required for our forming technique created minor problems with the interior envelope dimensions of the press. The internal surfaces of the blanking slide were enlarged to accommodate our tool set. The front to back bed opening was increased so that a straight cup dropout pattern was maintained for all tool stations.

One additional major change to the system was adding an external die coolant reservoir. Our anticipated goal was to minimize any secondary problems that could be generated by only using the small coolant reservoir within the pedestal of the press.

Tooling Accessibility

The replacement of perishable tools at the machine is now reduced to a die set removal procedure. The steps involved are:

(1) Draw slide should be at the top stop position
(2) Pull retaining pin out of the punch holder block
(3) Rotate draw punches 90 degrees to permit these punches to drop out of the punch holder block and remove them from the tool area.
(4) Remove front U-clamp from upper die shoe
(5) Remove toe clamps from lower die shoe
(6) From the rear of the press, tap the end of the die set so that it clears the rear U-clamp
(7) Disconnect two coolant lines
(8) The die set which weighs 65.5 pounds is now free to be removed from the press.

The machine operator can reverse this procedure to install another die set. The system is again functional and producing acceptable parts.

The ability to operate with such a simple system, as related to the machine attendant, is that all tooling accuracies are predetermined and maintained by the die sets. These units can be set up at a tool maintenance area and stored at the machine site ready for installation. With proper tool maintenance procedures, cup quality will remain consistant throughout tooling changeovers.

This design concept has a degree of flexible capability. It can readily be expanded to twelve tool stations, as the die sets do contain tool stations as multiples of three. This additional productive capacity should be evaluated by the ultimate user of such a system.

Test Run

The 1,000,000 piece contractual test run produced cups of excellent quality. The base thickness, outside diameter and wall thickness dimensions remained within the limits. Wall variation occasionally exceeded the .002 inch limit and drifted to a value of .0025 inch during ten of the five hundred fifty incremental inspection samplings established during this test production run.

Multistation Tool Set Design

An effective multistation tool set must have minimum "operator adjustment interfacing". The goal was to provide tooling that would produce quality cups and reduce the machine operator task to a "remove and replace" tooling procedure.

To accomplish this task, a two post die set that would contain the perishable tools and span the incoming strip was designed. This die set would be as narrow as possible so that the overall envelope width evolved from this study was 3.125 inch wide. Within this dimension, we were able to incorporate die coolant channels that would direct coolant over both the first (upper) and second (lower) draw dies. Our objective was to minimize heat buildup in the working tool area. A second coolant channel within this lower die shoe directs coolant to the blanking punches to again minimize heat buildup while simultaneously lubricating the blanking punch guide bushing.

The heart or accuracy of our tooling is the blanking punch guide bushing. By insuring the concentricity of each guide bushing in relation to the dies, our ability to produce quality cups is enhanced.

With all dies (blanking & drawing) concentrically oriented to this fixed guide bushing, both punches, blanking and drawing, are allowed to float laterally within their respective punch holders. Their guidance is, therefore, controlled during the working portion of their respective strokes by the blanking guide bushing. This guide bushing directly controls the blanking punch which in turn controls the draw punch.

The punch guidance arrangement minimizes the effect of lateral machine motion by the draw slide on a double

action press — a feature that is all important if wall variation is to be kept at minimal acceptable levels.

The tool set was, therefore, composed of four die sets as described above. The outboard die sets would contain three sets of perishable tools, while the inner two dies sets would contain two sets of perishable tools. This arrangement provided us with the ability to produce ten cups per press stroke.

All four die sets are of a common design so that die set interchangeability reduces tool inventory costs.

An adapter plate mounted to the face of the press blanking slide controls die set orientation. U-shaped clamps position and hold the upper shoe of each die set to this plate. Toe clamps retain each lower die shoe to the press bolster plate.

The press draw (inner) slide also has an adapter plate to accept the four punch holder blocks. These punch holder blocks slide into place on "L-shaped" rails for position control and are secured in this position by individual stop blocks.

The inner slide adapter plate is aligned to the blanking slide adapter plate prior to installation of tooling. This technique ensures and maintains the alignment accuracy of our tooling.

The wall variation did drift beyond the .002 inch tolerance up to a value of .0026 inch. The reason for this localized drift in wall variation is not easily ascertained. It occurred at stations located in three of the four die sets. Two locations are at the strip width extremities. The condition was self-correcting as evidenced by the acceptable quality on the inspection sheet immediately following the one in question. Tooling was not replaced during the run as a result of these wall variation values. The strip dimensions were not monitored in relation to the cup sampling so that this interrelationship could not be compared.

The base thickness remained within the .135-.140 inch range. Monitoring of the input material showed that it varied along one edge from .1405 to .1435 inch. Design parameter for input material was .140-.144 inch. The strip thickness to cup base thickness is not a direct relationship. Development testing indicated that side-wall ironing did affect cup base thickness to some degree. The magnitude of this phenomenon has not been ascertained. It is evident that cup base thickness values remain within the prescribed limits with the input strip material currently used in this developmental program.

Tool Failures

The tool failures experienced during this run were minimal. Three blanking punches were replaced due to a chipped cutting edge. This condition would produce an irregularity on the mouth of the cup which affects the additional cartridge case forming operations.

Evidence of brassing on the punches and/or dies was almost nonexistent. At the conclusion of this test run all the tooling was removed and inspected for any abnormal surface conditions. No evidence of any abnormalities was found. An observation was noted that the magnitude of the brassing had remained constant from early in the test run to the termination of the run.

Tool Wear

Prior to the start of this production run the perishable tooling was dimensionally itemized. Of prime interest was the I.D. dimension of the blank punch guide bushing (.7507-.7505 inch) versus the blanking punch O.D. dimension (.7502-.7500 inch).

The material for these guide bushings is AMPCO 18 bronze, which is a wear resistant hard grade of bronze.

Our before and after inspections did not indicate a definite wear pattern.

Web Scrap

The projected web scrap loss for a 10-ton tool set was calculated to be 32.8 percent. Further reductions in web scrap loss can be achieved. By reducing the incremental pitch length of the hole pattern and minimizing the edge web, 30 percent scrap figures will result.

Dimensional Characteristics

Waterbury Farrel developed a cartridge case cup manufacturing technique which is a simple but highly accurate system. The results of our 1,000,000 piece run provided substantial data indicating that repetitive desirable dimensional cup characteristics can be achieved.

Today's production techniques were studied and evaluated with the conclusion that a radical departure from current cup forming philosophy is not necessary. By applying sound tool engineering principles, this known technique can be refined and improved so that quality components can be produced on a continuing basis. In conjunction with this tooling technique, the design of the prime mover, a double action press, will reflect the tool design requirements and not place any restrictions on the capability of the tooling to produce quality components.

Further, production rates with regard to cups produced per stroke and the strokes per minute of the proposed press design can be higher than the parameters (1300) utilized for the test program. Materials as supplied from three brass suppliers produced dimensionally acceptable cups without tool set modifications. Web scrap for the test program was 36 percent, but this can be reduced to 33 percent for the production version of the system.

Electron Beam Lithography for Bipolar Devices

IC Fabrication Using EB Technology

by
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In distinct contrast with much of the currently published electron beam direct writing work that seeks to demonstrate improved device performance and packing density capabilities, the object of a Texas Instruments program for the Electronics Technology & Devices Laboratory of the U.S. Army Electronics Research and Development Command was to develop a manufacturing capability for standard bipolar circuits of conventional design using existing e-beam direct writing equipment. In particular, a pilot-line demonstration of significant yields of conventional 4-5 micrometer design rule integrated circuits which were fully tested to military specifications for performance, quality, and reliability was of paramount importance. Achievement of this objective then established a baseline for direct e-beam writing in production and provided a significant stepping stone for implementation of e-beam technology in VLSI circuit fabrication.

The vehicle used for this demonstration was a standard TTL 256 bit bipolar RAM using a single level metal, junction isolated, Schottky clamped bipolar process. Emphasis was placed on utilizing a new class of high speed electron resist in combination with selective plasma etching techniques to establish economical next generation VLSI processes. A vector scan, laser controlled e-beam direct writing system developed in TI's laboratories with fully automatic slice alignment was used for patterning of these devices. To determine that e-beam direct writing yields devices with no degradation in performance or reliability, optically patterned split lot controls were fabricated in parallel and used for comparative testing.

Greater Design Complexity and Flexibility

It has been demonstrated that e-beam lithography can be used to fabricate bipolar devices to military specifications with no yield degradation or damage. This program also has established an e-beam lithography baseline process utilizing high speed electron resists and plasma etching techniques for fabrication of bipolar microcircuits. These processes allow greater circuit design complexity and flexibility, leading to better performance, lower cost, higher reliability integrated circuits.

Long Exposure Times Limiting Factor

Since the invention of the integrated circuit, lithography has been the key factor limiting device yield, feature size, and chip size. Major improvements in lithography over the last two decades have resulted in significant cost reduction, better device performance, and greater device complexity. Electron beam writing systems using a computer to generate the pattern by controlling the deflection of the electron beam are attractive for rapid device design, mask fabrication, and high yield device processing because they permit delineation of microcircuit patterns from computer data. These e-beam systems are also advantageous for high frequency and high packing density microcircuit fabrication because they permit higher resolution and better dimensional and placement (alignment) accuracy than achievable with photolithographic techniques.

However, the major problem that has limited the implementation of e-beam direct writing on the production lines has been the long exposure time per wafer and associated overhead time. A long range program was initiated at Texas Instruments to increase the throughput of this type of instrument. The first step was to develop an electron beam machine for fabrication of master masks (1X) and reticles (10X). This instrument (EBMII) was implemented in the photomask production facility in 1974 and has been in operation since that time impacting master mask quality and turnaround. This e-beam system (EBMII) allowed a throughput of two to four 3 inch masks or reticles per hour and had a resolution of 1-1.25 micrometers and a pattern overlay accuracy of plus or minus 0.25 micrometers. For direct slice writing, the resolution and pattern overlay accuracy of EBMII was certainly adequate for the next two generations of device designs. However, a five times

NOTE: This manufacturing technology project that was conducted by Texas Instruments thru the U.S. Army Electronics Technology and Devices Laboratory was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ERADCOM Point of Contact for more information is Marian L. Evains (201) 544-2881.

improvement in throughput was necessary for economic considerations.

For these reasons, the program was divided into two parallel parts. One part was to begin development of a new high throughput e-beam machine (EBSP) and the other part was to develop the electron resists and the etching processes necessary for fabrication of micrometer and submicrometer design rule devices. This development could take place on EBMIII (duplicate of EBMII) in parallel with the development of the high throughput e-beam machine (EBSP). The first task in this part of the program was to develop the resists and the etching processes for fabrication of 5 micrometer design rule devices so that the basic e-beam technology could be established on a parity basis with photolithography. The establishment of a 5 micrometer design rule, full military specification, e-beam integrated circuit pilot line capability (device vehicle—256 bit bipolar RAM) was the main thrust of the project in addition to making improvements in e-beam machine throughput by implementing higher speed electron resists, developing automatic slice loading, and showing the feasibility of variable shaped beam (large beam/small beam) writing. Implementation of plasma etching and demonstration of e-beam direct writing 1.25 micrometer patterning capability for bipolar and NMOS devices were also accomplished as part of this project. The development of the high throughput e-beam machine (EBSP), with the exception of the automatic loader, was accomplished on an internal program.

E-Beam Capabilities

Several different types of e-beam direct writing systems have been developed in the past few years. The approach taken at Texas Instruments was to utilize dynamic focusing and a computer aided design deflection system to achieve large field coverage (6.35 x 6.35 mm) to minimize the step-and-repeat time required. A vector scan system was chosen because it is inherently 3-4 times faster than a raster scan system, but the full advantage is realizable only with the elimination of, or compensation for, eddy currents. This has been accomplished on EBMIII with the use of ferrite liners and compensating hardware and software.

A vector scan system is limited in throughput (Figure 1) by the writing rate, the exposure rate, and several overhead factors (pattern overhead, step-and-repeat time, load/unload, automatic alignment). The writing rate is a function of the pattern generator, deflection amplifier, and electron optics. The exposure rate is a function of the gun brightness and electron resist sensitivity. The writing rate and the exposure rate must be equal; thus, the slower of these two rates will dominate (Figure 2).

The exposure time can vary significantly in a vector scan system, depending upon the particular pattern to be exposed. Using both a positive and negative resist, the average area for a typical static or dynamic MOS RAM or bipolar RAM is approximately 25 to 30 percent of the total chip area.

The EBMII-EBMIII type of system was designed as a balanced system. The pattern generator electronics (interface), electron optics, and deflection amplifier were developed to allow a system bandwidth of 2 MHz allowing beam scan speeds of 5 micrometers per microsecond. This is an equivalent "data rate" of 20 MHz for 0.25 micrometer

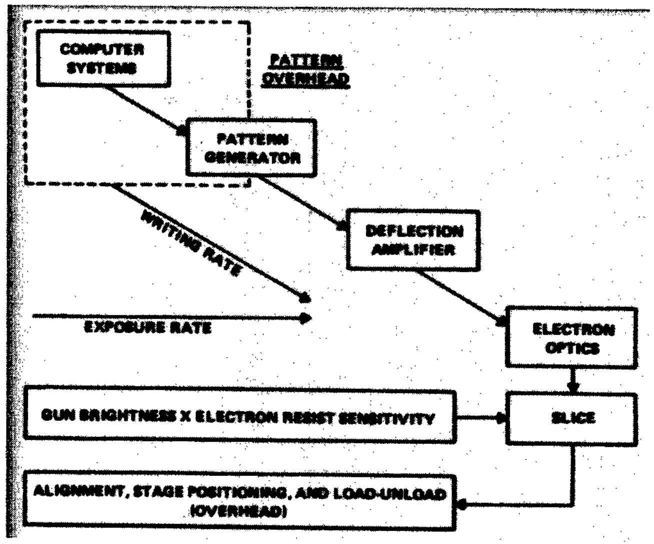


Figure 1

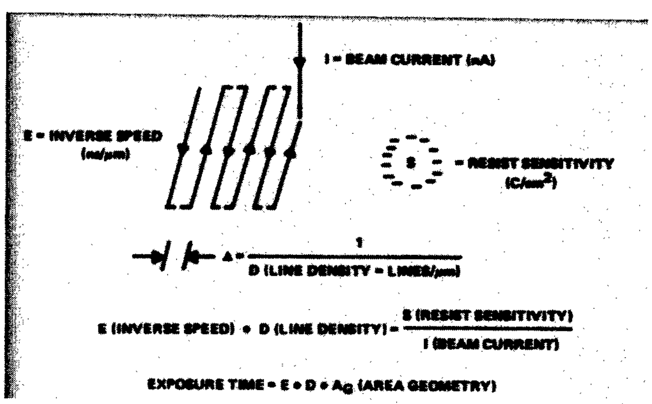


Figure 2

beam spacing. The optics system allows a resolution of 1.25 micrometers over a 6.35 x 6.35 mm field and submicrometer features over a smaller field size (about 2 x 2 mm). Large chip submicrometer devices are accomplished utilizing the laser interferometer capability of the system to "stitch" fields together ("mosaic" approach).

In addition to throughput and resolution, the other key factor of any imaging system is the pattern registration capability. Texas Instruments has developed and has used for several years a fully computer controlled automatic alignment system on the e-beam machines. Pattern registration for slice printing is accomplished by scanning the electron beam across reference marks in the scribe lines of each chip on the silicon wafer, detecting and amplifying the secondary and back scattered electrons, and processing this video signal to determine the correct position for the subsequently exposed pattern.

Alignment data is acquired by scanning the beam over fiducial markers which are etched 4-5 micrometers deep into the silicon slice at the very first step. This is accomplished with standard photolithography and carbon tetrafluoride-oxygen plasma etching for convenience. It is necessary to use two marker sets because the first set becomes distorted by epi-shift during the growth of the epitaxial Si layer. The second set is optically aligned to the first set and this limits the alignment of the DUF to the remainder of the device to about plus or minus 1.0 micrometers.

Pattern data for the devices is decomposed on an IBM 370 computer into trapezoidal figures. The decomposed figures are sized to allow for pattern growth during processing. The data is then transferred to EBMIII (Figure 3) through the use of magnetic tape.

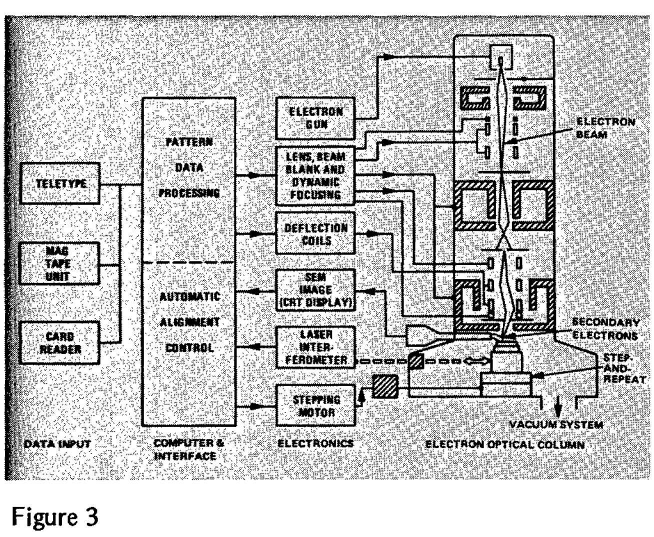


Figure 3

The average exposure time per level for the 256 bit bipolar RAM (3 inch wafer) was 8.2 minutes, but there was another 7.8 minutes of overhead primarily due to stage stepping time. The load/unload time refers to the new auto-loader developed on this project. This throughput is not the ultimate capability of e-beam direct writing. Also, a new e-beam system (EBSP) was developed at TI on a parallel program whose throughput is 5 to 10X better than that achieved on EBMIII in the fabrication of the 256 bit bipolar RAM (Figure 4).

Automatic Slice Loading

A computer controlled wafer handling system was developed on this project to increase the throughput of direct write e-beam systems, to eliminate the manual handling with vacuum or mechanical tweezers, and to reduce the large volume of air that had to be evacuated each time a wafer was loaded into or unloaded from the system. The basic goal of the slice handling system (Figure 5) was to add no more than 60 seconds to the total patterning time per wafer. Other design constraints were that the prealignment would be within plus or minus 1.5 degrees and no mechanically induced vibration would be present during slice exposure. This system allows load/unload of a wafer in about 40 seconds.

Automatic Beam (Large/Small) Control for High Density Patterns

Before the start of this project, the electron beam slice printer (EBMIII) was limited to exposing geometries greater than 0.1 mil at the same rate as geometries less than 0.1 mil. This results from the fact that for a fixed gun brightness, reducing the electron beam spot diameter by 2-4X results in a reduction in beam current of 4-16X. This means that a level which can be exposed in 10 minutes (excluding vacuum cycle time) using a 1 micrometer spot diameter, typical of exposure requiring normal resolution (0.1 mil), would take 40 minutes if exposed with a 0.5 micrometer diameter spot size. A small change in the spot diameter has a particularly negative impact on throughput.

It was determined that one way to sidestep this fundamental problem of electron optics was to expose all those geometries requiring high resolution with the small spot diameter, leaving the remainder to be exposed with the large beam diameter. Since the beam shifts slightly with a change in beam diameter, a realignment of the beam to a set of fiducial marks is necessary after every beam size

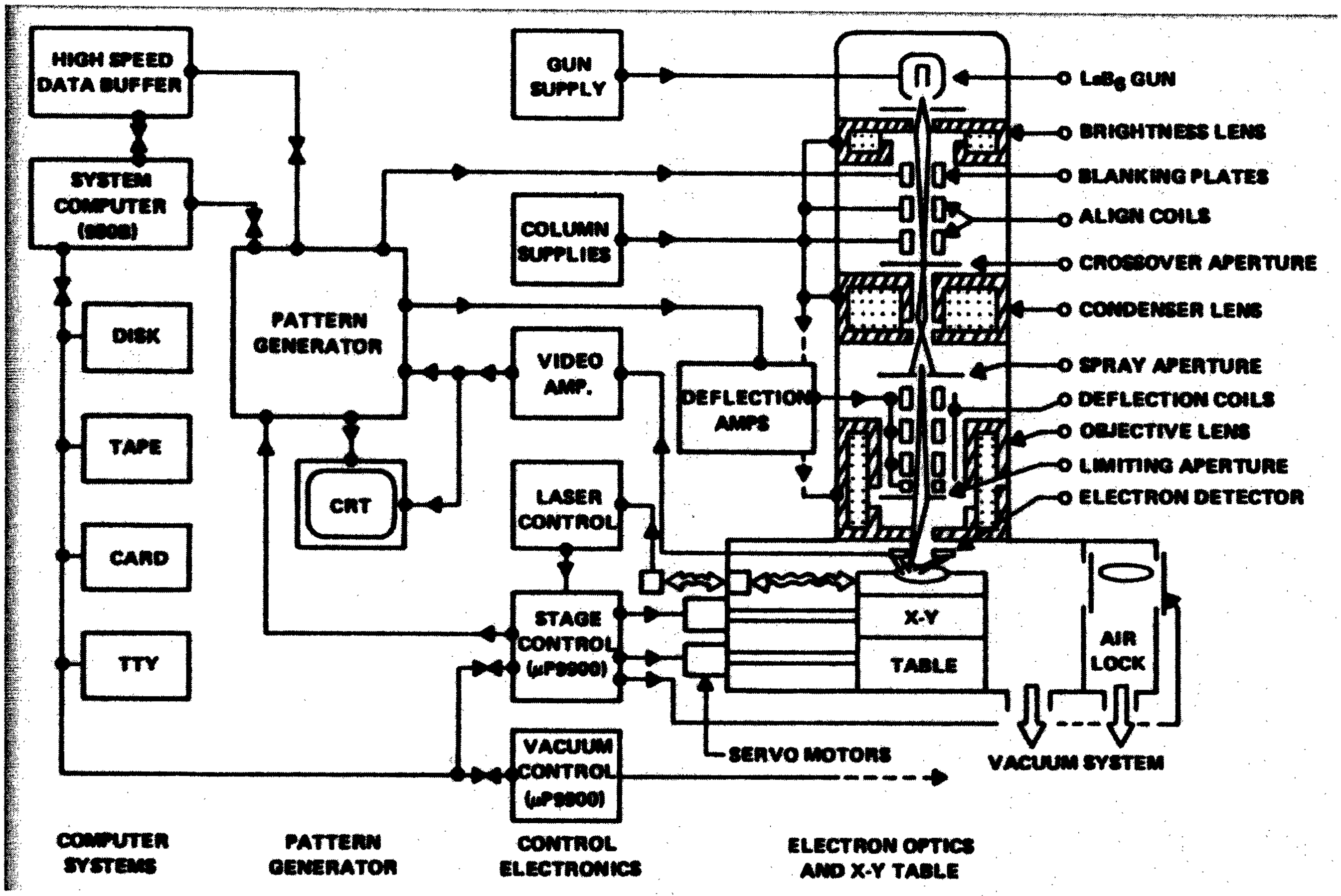


Figure 4

change. This requires a two pass process: alignment and exposure of pass one; and a change in beam size, alignment, and exposure of pass two. This process will significantly reduce exposure times for high resolution work, provided that the time required for stepping and alignment is small compared with the time required to expose the entire level with the small beam.

Implementation of this dual beam processing capability on EBMIII was only a matter of software development, because the hardware required to switch between two preset beam diameters already existed prior to the project. A sort on input geometries using size criteria was necessary to separate one level into two levels with two different resolution requirements. This data processing operation was accomplished on the IBM 370 to take advantage of level documentation available there. A 1 micrometer device was exposed with the dual beam technique and showed no image degradation due to two passes.

E-Beam Resist and Etching

Many of the desired properties and requirements for organic polymeric resist imaging materials are similar regardless of the exposure technology. Some of the more important properties that must be considered are outlined following:

Critical Factors in Resist Performance

Contrast	Glass Transition Temperature
Resolution	Molecular Weight
Sensitivity	Dispersity
Adhesion	Purity
Etch Resistance	Swelling
Undercutting	Solubility
Defect Density	Filtering
Film Uniforming	Stripping
Step Coverage	Shelf Life
Thermal Stability	Toxicity
Thermal Flow	Implant Masking

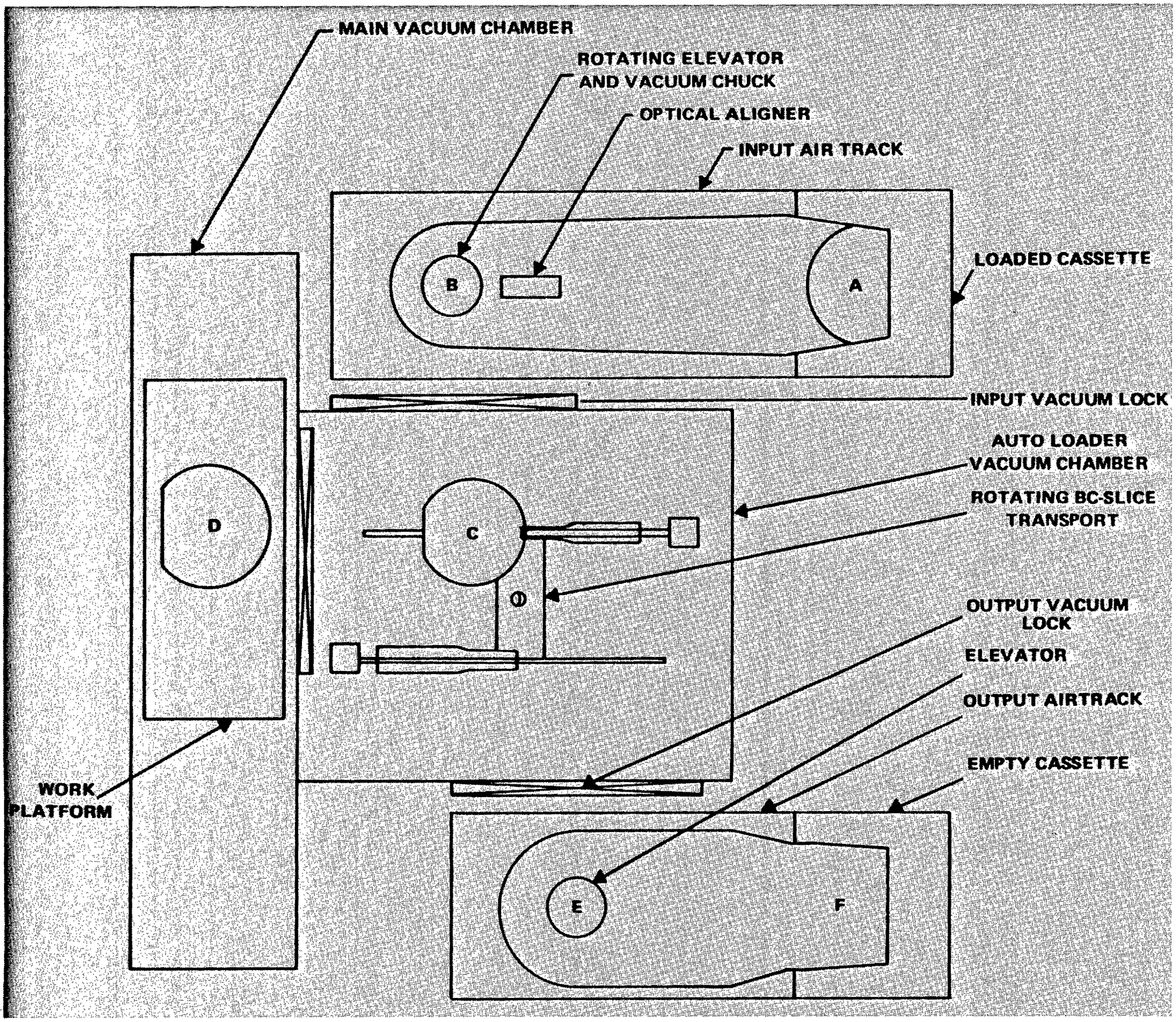


Figure 5

Due to the stringent requirements for an e-beam resist to be used in direct slice writing, no completely satisfactory resist has been developed. Some polymers behave well enough based on several of the criteria, but all fail in at least one area, especially where direct slice writing is concerned.

Positive resists have received the most attention and development. Only two positive e-beam resists—PMMA

and PBS—are commercially available, and both fail to meet TI's requirements. An extensive development program at TI has provided a family of resists—TI-303, TI-313 and TI-323—which can be and have been used for device fabrication. TI-313 offers the best advantages where processing requires dry etch processes, such as plasma and reactive ion etching, and was used extensively on this project.

Negative e-beam resists contain a reactive moiety, such as epoxy, vinyl or allyl group, which, on exposure to e-beam irradiation, form a crosslinked gel. Swelling of this gel during developing is the major limitation of most materials considered for e-beam resists. The most widely used commercially available negative e-beam resist is COP. The major shortcomings of COP are marginal dry etch resistance and adhesion. TI uses a negative resist, TI-309, which was developed internally to match the e-beam exposure system and device processing.

Pattern Transfer (Etching)

Etching processes for pattern formation in VLSI device layers must meet exacting requirements: directionality, selectivity, uniformity, process control, and freedom from damage and contamination to enable practical, well controlled pattern transfer of features 1.25 micrometers or smaller in size. Texas Instruments has pioneered the development of the parallel plate, radial flow plasma reactor for the express purpose of providing improvements in uniformity and process control (Figure 6). The combination of depletion of active species as the radial flow proceeds inwardly, balanced with an electron density which decreases towards the outer walls, results in the capability to etch or deposit films with exceptionally good uniformity and control over an area large enough to etch several dozen 3 inch wafers. As this technology has matured, plasma conditions and reactive etching gases have been formulated to produce practical etch rates for all the important semiconductor films to be patterned. More importantly, it has been shown that the etching can be done with almost perfect directionality—i.e., vertical etch rates can be obtained that are at least ten times greater than the lateral or undercutting rates. This allows submicrometer patterns with very high width aspect ratios to be etched and placed very close to each other. The directionality arises from the enhancement of the reaction of the reactive species which are absorbed on the wafer surface by bombardment of positive ions from the plasma. Slices in contact with the plasma naturally attain a negative potential with respect to the plasma, and positive ions with mean free paths on the order of millimeters are accelerated perpendicularly towards the surface. Because the voltages are limited to a few hundred volts, the ions do not have enough momentum to cause sputtering, but can promote dissociation and transfer energy to the surface chemical reactions.

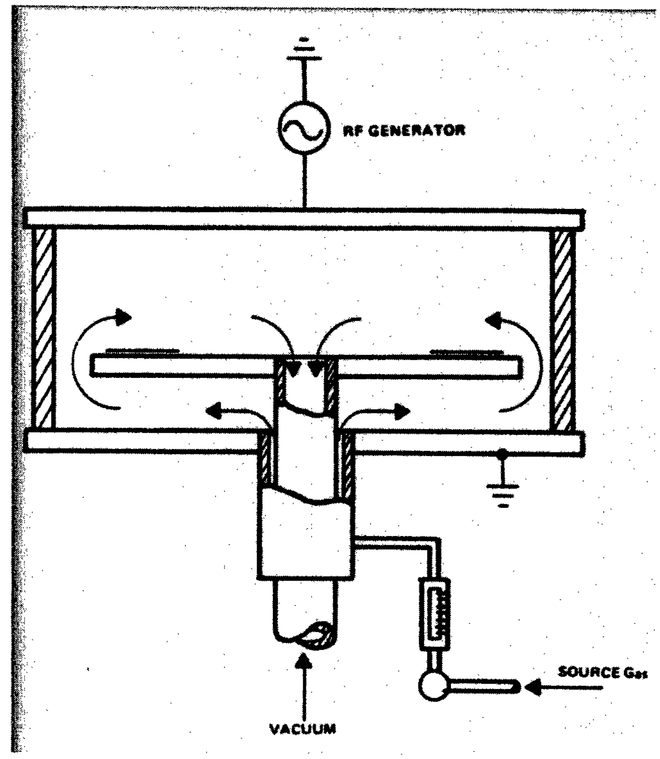


Figure 6

Reactive ion etching is a technique similar to parallel plate plasma etching, except that it requires lower pressure and the slices to be etched are placed on an electrode whose negative bias with respect to the plasma can be independently controlled. Control of the positive ion bombardment energy is clearly an advantage that allows more versatility in the reactant gases that can be used and therefore provides the opportunity to develop processes with a great deal of selectivity.

Practical implementation of plasma or reactive ion etching requires processes with acceptable differential etch rates (selectivity) between the masking material and the material to be etched, as well as between the material to be removed and the substrate from which it is to be etched. It is therefore significant that Texas Instruments has developed practical processes for selective etching of

such systems as poly Si on silicon dioxide; silicon dioxide on Si; and Mo, Te, and W on silicon dioxide, for example; further, they have demonstrated these processes with actual integrated circuit fabrication. For instance, the all e-beam patterned 256 bit bipolar RAM has been successfully produced using a selective oxide plasma etch at every level.

Device Fabrication

Although there are many possible bipolar processes that could be used in conjunction with e-beam pattern definition to build memory devices, the process chosen for this program was the single level metal, junction isolation Schottky process which is used by Texas Instruments in building the SN54S/74S Random Access Memories. The particular device selected for this program was the SN74S-201A, a monolithic TTL memory featuring Schottky clamping for high performance with fast chip select access time to enhance decoding at the system level. This device contains a 256 bit fully static random access nondestructive readout memory. The memory, if fully decoded, requires only eight address lines to select one of 256 storage locations. An additional line, write enable, is provided to enable the memory to modify the stored data. Separate data input and data output lines are provided for minimum interaction between input and output functions.

Three chip enable lines are provided to simplify the decoding required to achieve the desired system.

The basic logic diagram is shown in Figure 7. The memory matrix is organized in an array of 16 rows and 16 columns. The address inputs A, B, C, and H go to a 4-to-16 line decoder and determine the memory row selected. The terminal connections for the 256 bit RAM are shown in Figure 8.

The SN74S201A utilizes inverted cell memory elements to achieve high densities. The cell (Figure 9) is basically two cross coupled inverters and two sense diodes. Information is written into the cell or read from the cell along the sense lines. The cell is enabled or disabled using the word line. When the word line is low, information can be read from or written into the cell. When the word line is in a high state, the cell is disabled and no information can be read or written.

The circuit schematic for all of the inputs is shown in Figure 10. This input circuitry was designed to give very low high-and-low-level input currents and very high performance. The low input currents allow higher fan out capability in an entire memory system. The use of Schottky diodes and transistors in the inputs increases the performance over non-Schottky devices. The inputs also have clamping diodes to protect the circuitry in case the input voltage should go negative.

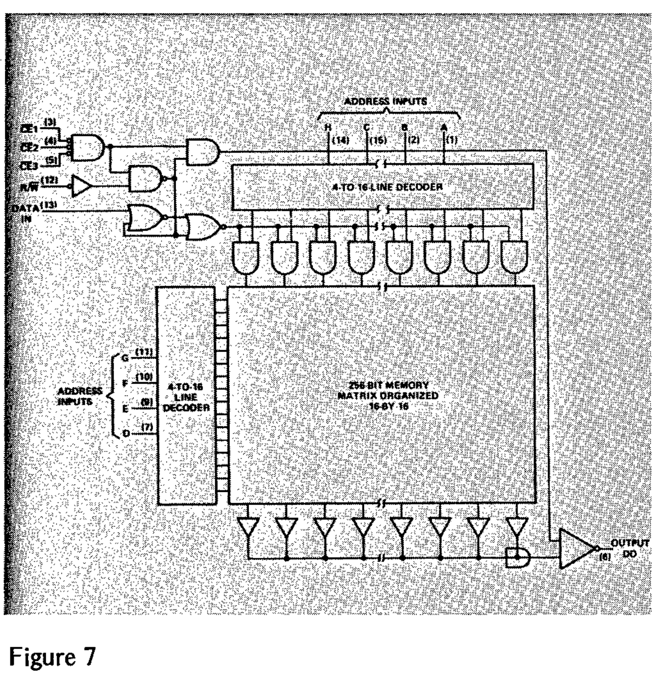


Figure 7

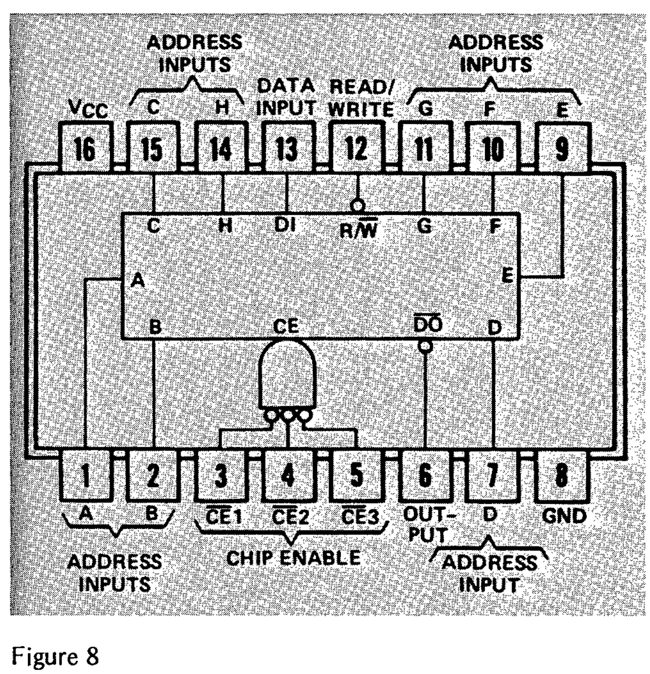


Figure 8

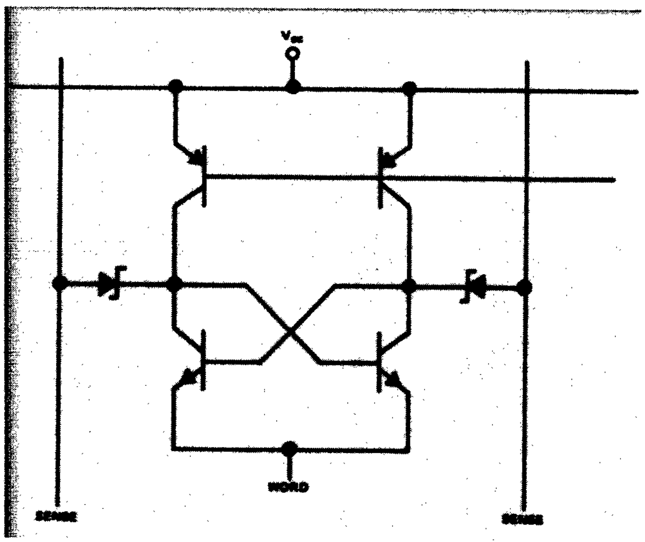


Figure 9

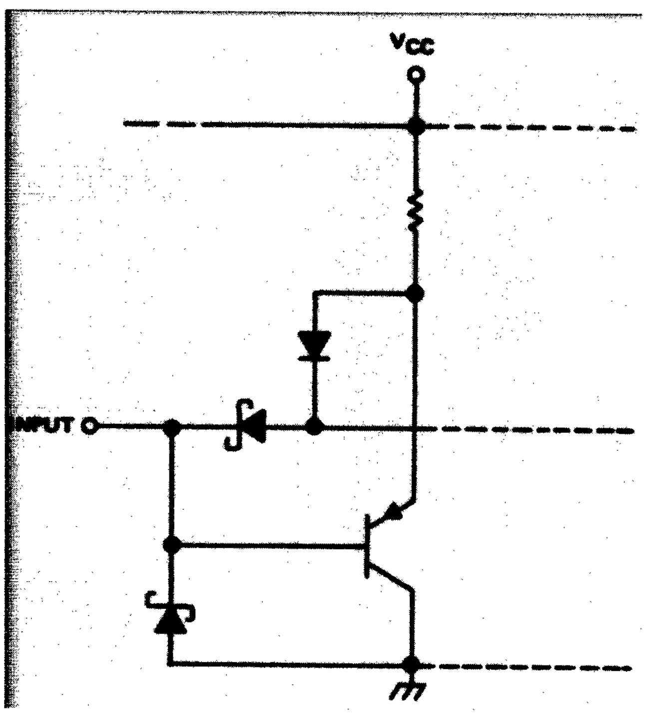


Figure 10

The SN74S201A has a three state output (Figure 11) that offers the convenience of an open collector output

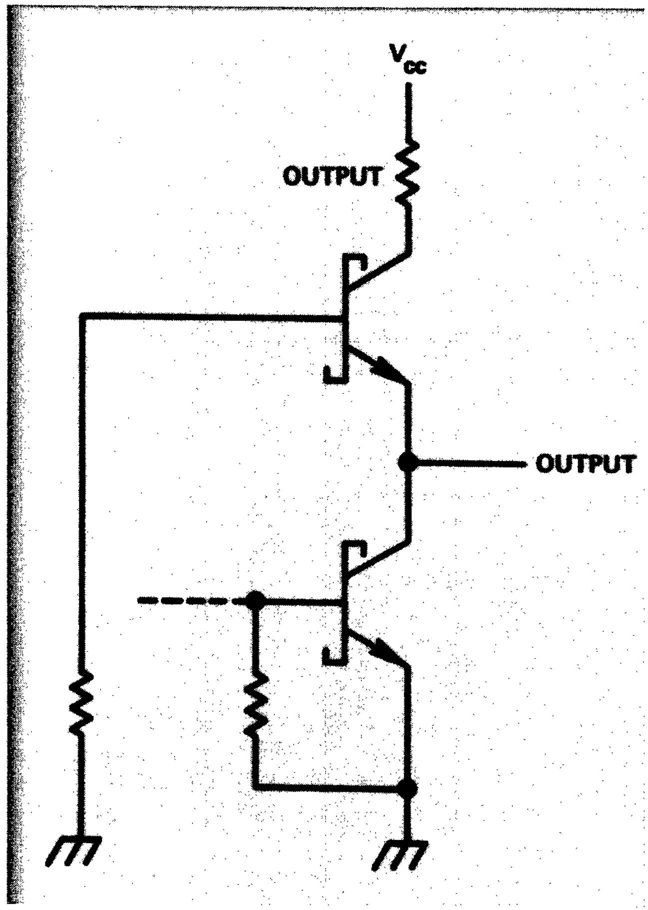


Figure 11

with the speed of a totem pole output. This output circuitry permits the output terminal to be bus connected to other similar outputs, yet it retains the fast rise time characteristics of a TTL totem pole output.

Lower Cost and Higher Reliability

E-beam lithography can be used to fabricate bipolar devices to military specifications with no yield degradation or damage. No conclusive yield improvement results were demonstrated since this device is not limited in yield by lithographic factors, but rather by diffusion processes. Processes developed here will allow fabrication of many high density VLSI devices and have already allowed fabrication of a 1 micrometer minimum feature size e-beam 4 bit microprocessor. E-beam technology will allow both greater design complexity and flexibility and, thus, better performance, lower cost, and higher reliability integrated circuits.

Feasibility Proven, But Expensive

Optical Gap Inspection Tester

by
Omer L. Hageniers
(Diffracto, Ltd.)

Bhadrayu Trivedi
(U.S. Army Armament R&D Command)

The present generation of tank armament requires inspection for critical dimensional gaps (as small as 0.002 in.) between assembled components. At present, the inspection of gaps is conducted manually with feeler gages, a technique that is unreliable for gaps of less than 0.005 inch.

This project was initiated to achieve better accuracy, greater reliability, and faster inspection rates for 105 mm HEAT-T projectiles M456 by developing an optical technique to measure critical gaps automatically. Following a successful feasibility study conducted by General Electric, the U.S. Army Armament Research and Development Command (Tank Infantry Systems Division) contracted with Diffracto, Ltd., to design and build a prototype of an optical gap inspection tester. When the prototype proved to be inadequate for use, a follow on effort was initiated in an attempt to resolve the technical difficulties previously encountered.

Diffracto's design concepts for both the prototype optical gap tester and the standards used to test the prototype were submitted to (and subsequently approved by) ARRADCOM. The standards were designed to conform to the requirement for a gap which would not ". . . be wider than 0.002 in., greater than 0.125 in. deep, and less than 90 degrees." The standard design data are shown in

NOTE: This manufacturing technology project that was conducted by General Electric thru Diffracto, Ltd. was funded by the U.S. Army Directorate for Manufacturing Technology, DARCOM. The ARRADCOM Point of Contact for more information is Donald Fischer (201) 724-5957.

Table 1, while the actual measured dimensions are given in Table 2.

Following a preliminary proveout test conducted by Diffracto and witnessed by ARRADCOM, the prototype tester was accepted by ARRADCOM and shipped to Milan Army Ammunition Plant (MAAP) for final proveout testing.

Equipment Encompasses Three Systems

The gap testing equipment consists of three different systems: mechanical, optical, and programming. In the mechanical system, the projectile is hand loaded onto bearing rollers against an end slip roller to an axial tolerance of plus or minus 0.030 in. One of the support bearings acts as a drive roller for an optical incremental encode with a 3.03 to 1 drive ratio and 360 counts per revolution. Initially, the encoder was rotated at 60 rpm by a dc gear motor.

The optical technique employed reflects the backlit gap onto a linear photodiode array by means of an oscillating scanning mirror which sweeps the image of the gap across the array. The mirror has analog position feedback and thermal compensation.

The scanning mirror and linear array are synchronized so that a raster is generated with line spacing of 0.001 in. To make the array with elements on a 0.001 in. center read accurately to 0.0001 in., the optical magnification of 4 is multiplied by an electronic magnification of 2.5 (Figure 1). The programmer monitors and controls the system.

Driven by a master clock in the computer, a reticon linear/photodiode array is placed at the image plane of the imaging system. The scanning mirror and array are synchronized by the master clock so that a raster is generated with line spacing of 0.001 in. The array clock is fixed at a specific frequency. The fast and slow rotational speeds are nominal (one revolution per second and 1/12 revolution per second, respectively).

One mirror cycle contains 160 array scans. At 512 array elements per scan, each mirror cycle takes 81,920 clock pulses (512 x 160) per mirror cycle. At the fast rotational speed, the array reads 5 frames per revolution at a resolution of 72 degrees. At the slow rotational speed, the array sees 60 frames per revolution at a resolution of 6 degrees.

The elements are sequentially read for each array scan producing a voltage charge from 0 to 2.5 mV. A total of six thresholds are set between 200 mV and 700 mV at 100 mV

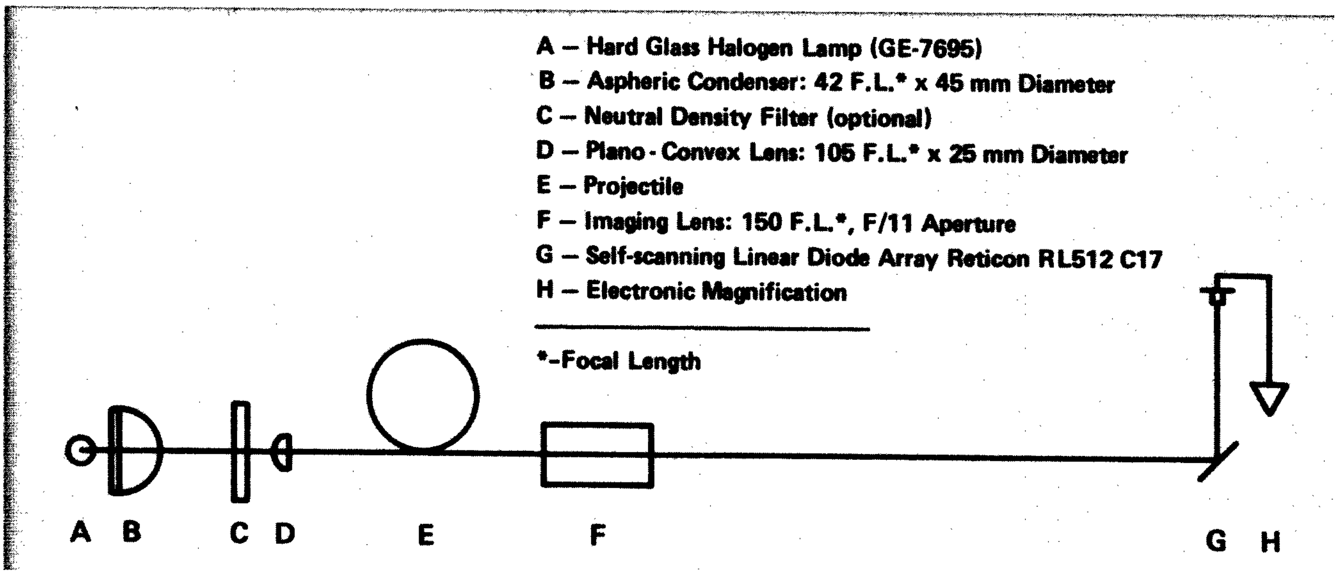


Figure 1

Type	Width, in.	Depth, in.	Angle, %	Remarks
1	0.0017 – 0.0001	0.126 + 0.001	360	Accept
2	0.0022 – 0.0002	0.122 + 0.0002	360	Accept
3	0.0022 + 0.0002	0.126 + 0.001	83 + 1	Accept
4	0.0022 + 0.001	0.126 + 0.001	97 – 1	Reject

Table 1

intervals using hardwired electronics for level detection. For each array scan, the sum of the number of elements crossing each threshold is used as a basis for gap width. The multiple thresholds provide the electronic magnification which increases the resolution. Since the edge of the image has several elements in transition, this method approximates an integration of the area of the signal. Although an electronic magnification of 2.5 is required, six thresholds are used since cumulative errors reduce the accuracy of the system.

The sum of the counts per level for each scan is read into a storage register of a Diffracto designed controller based on an eight bit Intel microprocessor. Since the acceptance criteria per scan vary down the depth of the gap, the array count storage register is compared to a permanent register scan by scan. Two consecutive scans indicating a width less than the criterion makes the frame acceptable. At the 60 rpm rotational speed, two consecutive rejected frames indicate a rejected part. Wraparound of one frame is required to complete the gaging.

Problems Encountered

Before acceptance, it was found that Diffracto had not made the equipment safe (i.e., required explosion proofing had not been included). However, because of economic considerations, Milan Army Ammunition Plant agreed to make the necessary changes.

The standards produced to meet the dimensions and tolerance required by the contract do not produce the same results as production parts because the surface finish of the standards is an order of magnitude smoother. The roughness of the production part is a result of machining marks which act as light traps and reduce the amplitude of the light striking the array. As a result, the standards did not represent the true component.

The early design of the M456A1 employed a one piece obturation device which Diffracto used to develop the standards. However, during the development of the optical gap inspection tester, the design of the M456 was changed to incorporate a two piece obturation device consisting of an obturator and a seal (Figure 2). (Diffracto was not aware of this modification until the proveout test.) With the one piece obturator, at least an 0.005 in. shoulder was available for use as a reference surface to check the depth of the gap. With the two piece obturator, the reference surface is hidden, making it more difficult to measure the depth of the gap.

The light passing through the gap is in a straight line with a tangent to the gap. Since the arc formed by the light source is smaller than the expected arc of 90 degrees, the equipment failed to meet the drawing requirement.

Milan AAP's modification of the equipment to provide explosion proofing included placing a window between the source and the scan which caused signal degradation and attenuation and reduced system reliability below the acceptable limit.

It was concluded that equipment modifications were required for better efficiency and greater reliability. The standard design needs to be changed to accommodate the two piece obturation device and provide an adequate reference surface. Also, the standards should not be machined to the point where the surface of the standards is smoother than that of the actual M456 hardware. Further, the requirements for the standards should be changed to read, "The gap shall not be wider than 0.002 in., deeper than 0.125 in., and 360 degrees."

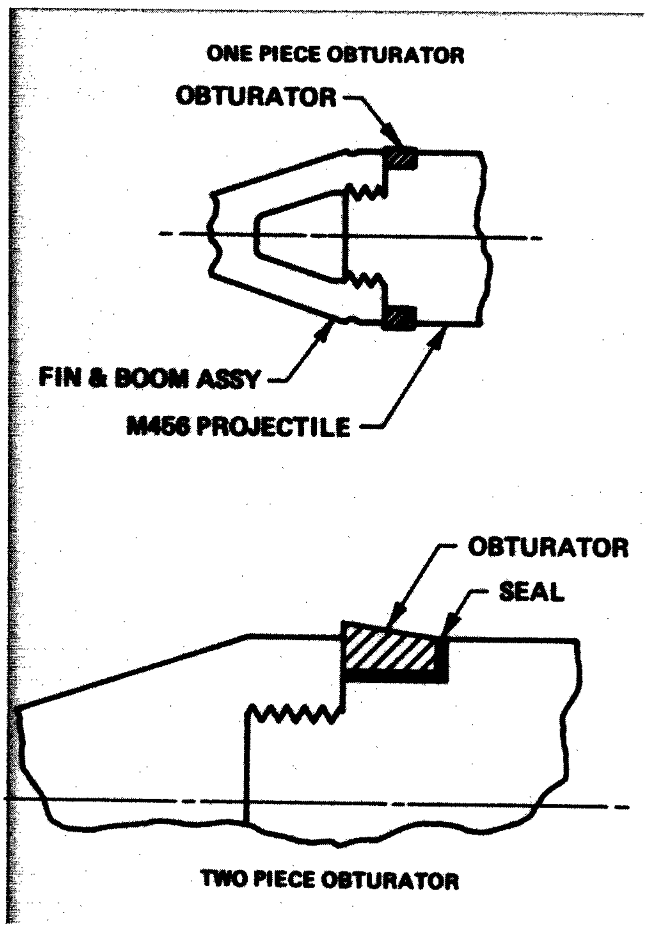


Figure 2

Modifications Undertaken

In an attempt to modify the optical gap inspection test to meet the requirements for accuracy and reliability, the following actions were taken.

Having already concluded that the light source needed to be replaced and the sensor realigned, ARRADCOM and Diffracto further evaluated the prototype optical gap inspection tests using production parts for testing. The signal processing threshold levels required adjustment to set their values to those previously documented. These adjustments were made before the testing was begun.

Testing

Gap data were recorded for five parts under various conditions. The first part examined was the standard. Gap data were recorded with the parameters at their current gage settings as the control sample data. Sensor parameters were varied in an effort to evaluate their effect on the quality of the gap data. Since the gap image could be properly focused only at the top or the bottom of the gap, it was decided that the gap data would be taken with the image in focus at the bottom.

The second parameter changed was the position of the mirror swing to record as much gap depth data as possible. The third parameter altered was the frequency of the array clock, which was decreased to test how much more light could be seen at the bottom of the gap.

Type	Width, in.	Depth, in.	Angle, %	Remarks
1	0.0018	0.128	360	Accept
2	0.0022	0.123	360	Accept
3	0.0023	0.126	83	Accept
4	0.0022	0.127	97	Reject

Table 2

The top of the gap was not clearly defined due to the poor focus over that region. The swing-back action of the mirror was seen in the first few readings of all the data samples recorded. Indications were that better repeatability of gap data was obtained at the slower array clock frequency. The tabulated data also showed that the position of the mirror swing had no effect on the data at the slower array clock frequency and that gap data can be read at least 18 scans deeper into the gap. Gap data for two samples demonstrated that 115 scans were required to scan the entire gap depth, which translates to a depth per scan of approximately 0.0011 in. with an array clock frequency of 333 kHz.

In one experiment, it was found that slowing the array clock frequency increases the sensitivity of the array to light, thus, more light can be seen at the bottom of the gap.

Since it was desirable to record as much gap data as possible, the remaining part data samples were measured with the lower mirror swing positions and, with one exception, an array clock frequency of 200 kHz.

Next, gap data of the known master to that of a production part measured under various conditions was compared. Feeler stock shims of 0.002 in. and 0.003 in. were used, and the 0.002 in. shims were repeatedly removed and reinserted. Data were taken with and without removable obturator rings. The repeatability of the data and the effect of raising the array clock frequency to 400 kHz were also tested. The gap data were found to be repeatable and consistent with the expected, and, in all cases, the depth to which the gap could be seen extended to at least 0.133 in.

More Problems Encountered

Diffracto observed that the present condition of the seal (P/N 9327359) causes difficulty with gage operation. In many assemblies, there was a flash on the seal edge which overlapped the gap area, preventing accurate viewing of the gap. Also, the second obturator band is not tight and has a tendency to slide over the outer obturator band, obstructing the gap area. Also, the obturator band which is glued to the body may have excess glue near the edge, blocking the gap area. A mechanical means will be required to keep the obturator ring to one side of the gap and prevent its blocking the sensor's view.

During investigation of additional modifications, the light source was replaced and the sensor realigned. The signal processing threshold levels required adjustment to reflect previously documented values.

The optical window used in providing explosion proofing must be replaced by a window of superior design and construction because the present window causes too much signal degradation and attenuation.

Modifications Too Costly

The change from a one piece to a two piece obturator on the M456 complicates the material handling/holding fixturing of the equipment. In addition, changes to design, inspection requirements, and process controls for assembly of the obturator might be required to obtain full use of the tester. Also, and of extreme importance, costs to modify the equipment are almost as much as originally spent to procure the equipment.

Based on the technical difficulties anticipated and the belief that modification of the equipment would be more costly than is justifiable, a recommendation was made to terminate the project. However, the technology may be useful for other projectiles where measurements of unobstructed gaps are desired.

For Low Volume, High Mix Production

Flexible Manufacturing System Evaluation

by
Scott R. Gourley
FMC Corporation

A flexible manufacturing system now is operational at the FMC Corporation plant in San Jose, California, where the Bradley Fighting Vehicle is in production using one of the U.S. Army's most advanced facilities. The system is setting new standards of efficiency and cost effectiveness, as expected several years ago by the planners of the project.

FMC Corporation's Ordnance Division, a designer and manufacturer of tracked aluminum vehicles, recently introduced the M2/M3 Bradley Fighting Vehicles (BFV) into production. This program required the largest tooling and facilitization effort the division had undertaken since introducing the highly successful M113 program in 1960.

In comparison to the M113, the BFV was a completely new vehicle, more complex and with twice as many manufactured parts. Because of increased part mix and reduced production rates compared to the M113, the BFV parts tended to be processed in the machining department on a batch basis through shops organized by function. Even at lower production rates, the practice of using standalone conventional and N/C machine tools for complex workpieces was operationally and economically ineffective. If the BFV's product life cycle, like that of the M113, eventually reached higher production levels than those required initially, the need for improved manufacturing efficiency would be even more critical.

NOTE: This manufacturing technology project that was conducted by FMC Corporation was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The TACOM Point of Contact for more information is David Pyrce (313) 574-6567.

Initial Concept Studies

Under a program funded by the U.S. Army Tank Automotive Command, FMC has looked into opportunities for reducing the vehicle cost. As part of this effort, a group of machined parts was identified for detailed analysis. Most of the parts were components in the drive train, weapon positioning, or suspension systems and ranged in quantity from one to twelve units per vehicle.

The first concept studies involved special purpose boring/milling machines and head changers. Their advantages included improved part processing to meet close tolerances and improved equipment utilization; and reduced labor, lead time, in-process inventory, setup, scrap, and rework.

Disadvantages of these concepts included difficulty in determining machine configuration and tooling costs due to potential variations in production rates; equipment lead time; no backup capabilities in the event of machine failure; and inflexibility to handle major design or part mix changes.

Company decisions and other complications affecting the early development efforts raised several important issues.

First, many components on the M113 program were being processed on special purpose machines and a transfer line was being used for hull machining. The inflexibility of the M113 equipment contributed in part to the capital equipment requirements for the BFV program.

Second, Ordnance Division had received authorization for a parts manufacturing facility that would focus on manufacturing parts on a low cost basis for the BFV program. To accomplish this objective, the division would have to improve its manufacturing technology and provide flexibility to adapt to increased production rates. The facility was to be located remote from the main complex and limited in its potential size.

Third, part of a producibility effort resulted in tolerance changes that offered more choices on the types of machining that could be used to process the parts. An investigation of FMS technology was initiated using the same group of high cost parts involved in the previous study. Vendor concepts were requested and two were selected as having the highest potential. One concept would require three horizontal machining centers and two vertical turret lathes. The second concept would consist of horizontal turn face boring machines instead of vertical turret lathes. The latter configuration promised reduced part handling and fixture requirements because the part would always be machined in the horizontal attitude; however, the turn face bore machine, expected to be a standard machine tool by the vendor, had yet to be built.

More Expertise Called For

To properly assess FMS configuration issues and to comprehensively understand the dynamics of an FMS system, FMC worked in conjunction with Charles Stark Draper Laboratories Incorporated, Cambridge, Massachusetts. Draper Labs is involved in research in areas of expertise which include industrial automation, advanced electronics, and advanced inertial navigation systems. Thus, FMC drew upon Draper's expertise in analyzing FMS technology relative to its production requirements.

Data Base Built

Since the configuration and analysis of an FMS is non-initiative, Draper Labs had developed computer programs which provided capability to simulate many of the dynamics of an FMS machining system. For FMC, a data base was established from which various configurations of an FMS could be created and simulated. Cutting speeds and feeds by material type were defined for the machining processes: rough milling, finish milling, contour milling, drilling, tapping, counter boring, reaming, woodruff key milling, semifinish boring, finish boring and form tool milling. Operating parameters for each type of machine were also determined for horesepower, thrust, torque, maximum spindle RPM, maximum feed rate, maximum traverse rate, tool change time, rotary table index time, pallet shuttle time and tool storage capacity.

Preparing process plans for each part was complicated because, in some cases, a part had multiple processing methods that varied according to the type of machine being used. This complication significantly increased the number of FMS configurations that could be created. The process plan, consisting of machining operations required to complete the part, included the following data: operation number, feature machined, number of features machined, tool type (or machining process), tool diameter and/or number of teeth, length of cut, machine type and

material. Fixturing and tooling requirements consisting of fixture concepts, number of fixtures, part load/unload time, number and types of tools, and tool setup time were established for each part.

From the data base, machine time for each part was generated. This data was used with production rate variables—vehicles per period (shipset) and parts per shipset (part mix)—to generate the following information:

- Total machine cycle time by part and shipset
- Cycle time for each machine type by part and shipset
- Distribution of the machining cycle time among the machining processes by part and shipset
- Number of tools utilized in total and in each machining process by part and shipset
- Total number of tool changes per shipset
- Number of unique tools
- Distribution of shipset cycle time among the machine cutting, tool changing, tool positioning, table indexing and pallet shuttling activities
- Tool setup time by part and shipset.

This information was used to determine the approximate number of machines necessary to meet the selected production rate. Configuration of the system was further assisted by a batching and balancing algorithm that allocated parts to specific machines based on the number of tools used by the part, part cycle time, and tool capacity of the machine. The following additional information was required for each configuration in order to run the FMS simulator:

- Number of load/unload stations
- Material handling path and nodes
- Routing path of fixtures
- Machine failure frequency
- Due dates used by a scheduling algorithm to feed parts into the system.

The simulation model was able to establish system throughput, as well as utilization of the machine tools, material handling carts, and load/unload stations.

Analysis of these simulations significantly increased insight into the FMS approach. Machine requirements based on part processing methods could be better understood.

As the impact of production rate changes were more accurately determined, confidence in establishing system size and cost increased. Productivity of the system was equal to or greater than dedicated and special purpose machining alternatives.

Opportunities for improving the FMS configuration by changing part processing methods, fixturing, and tooling were identified.

System Configuration

Subsequent company decisions affected project development when it was decided that the FMS would be located in the remote parts manufacturing facility. This relocation was considered advantageous because it would make the FMS the cornerstone of advanced manufacturing technology at the new facility. Since the facility was considerably smaller than the main complex, management visibility would be higher, thereby insuring that resources would be available to support the installation, startup, and operation of the system. At the same time, some FMS parts were slated to remain at the main complex for machining in dedicated manufacturing cells. A major reconfiguration of the system was required because these parts represented over one-third of the machining load.

Adapting to the part mix changes required FMC and Draper Labs to identify additional parts for machining on the FMS. A parts coding system developed during the planning stages of the parts manufacturing facility was used to search for potential FMS parts. Prismatic and rotational parts were analyzed for suitability on the FMS. In addition to machine run time, the number and lengths of setup were considered in determining a parts potential.

Once a group of parts was selected, process planning, tooling, and fixturing data was prepared. Simulations of the FMS were run with part mix being an additional variable. The results of the simulations showed an imbalance of load between the machine types. There was not enough cycle time to justify more than one machine with turning capability, and it became questionable whether such capability should be included in the FMS. The proposed vertical turret lathe, which required additional fixturing and part handling in order to present the part in both the horizontal and vertical attitudes, was not regarded as an optimum method for processing the parts. The turn face boring maching was considered risky since the first unit had not yet been built. The FMS was considered complex enough without the compounded problems of a new machine tool and its associated debugging. Also, with only

one turning machine, neither alternative could provide backup within the system. Concurrently, backup was becoming more of an issue because the parts were destined to be machined in the remote parts manufacturing facility, and resources at the main plant would not be available.

Further simulations were performed to determine the impact of removing the turning capability. These simulations involved removing some parts and reprocessing others to perform all the machining operations on horizontal machining centers. The results showed that a system of five identical horizontal machining centers could be configured around twelve parts. The configuration was considered optimum based on all simulations run to date. Productivity would improve significantly over the batch processing method. The deviation from current processing methods would be minimized so that the FMS could benefit from the experience gained on the parts to date.

While conventional processing methods required multiple machine/operations to complete the parts, the new method would maximize the setup, material handling,

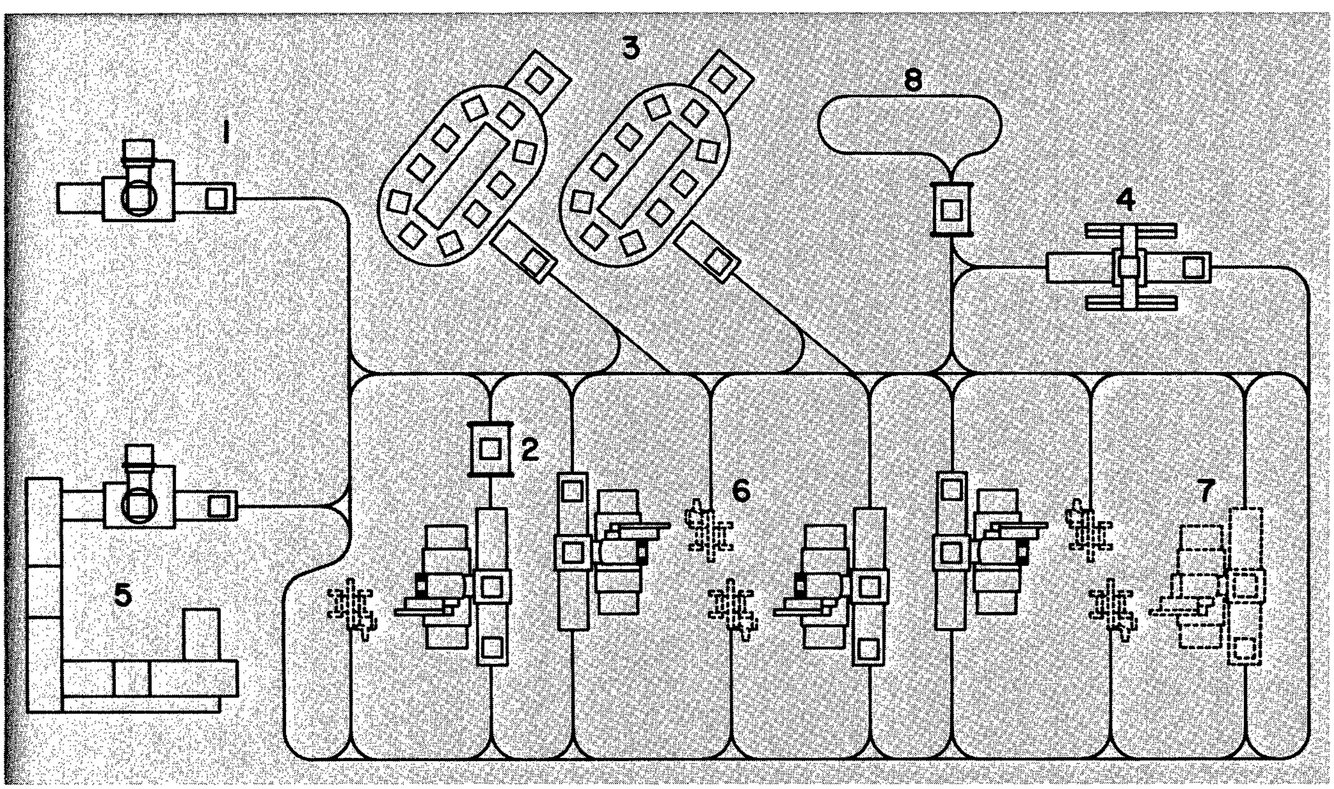


Figure 1

scheduling, and inspection advantages of the FMS. The number of tools would be minimized to allow incorporation of a significant backup feature into the system. By adding another set of tooling, all parts could be processed on at least two machines. This backup would greatly increase the system's flexibility to produce shipset quantities of parts without reconfiguration or rescheduling in the event of machine downtime.

Automated Wire Guided Vehicle

The Automated Wire Guided Vehicle (AWGV) was selected because it provided the greatest opportunity to integrate the FMS technology into other manufacturing activities within the parts manufacturing facility. However, this selection still required additional system design changes that addressed the AWGV's inherent disadvantages. Special attention was paid to the control of coolant and chips. Guarding was added to the machine tool that completely encloses the part and fixture during machining. Collection trays were added to the AWGV to prevent coolant and chips from landing on the floor as they fell off the pallet/fixture during transport.

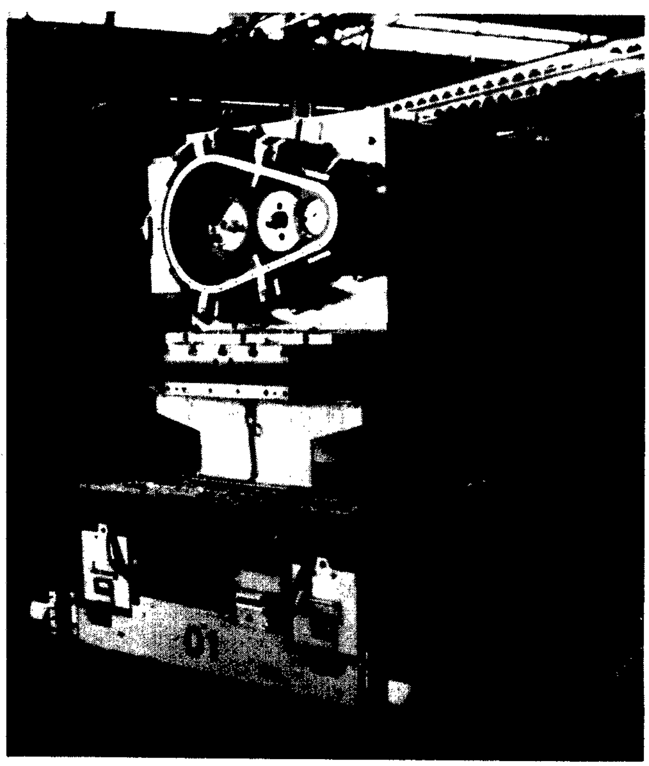


Figure 2

A new load/unload station that would confine and transport coolant and chips away from the AWGV path was designed, with a capability to tilt the pallet/fixture 90 degrees and rotate it to ease part loading/unloading. The resulting design (referred to as an orient/wash station) eliminated the need for the automated parts washer. Specifications for the AWGV were also developed.

FMC needed the capability to traverse surfaces not suitable for guide wire installation such as steel gratings and plates. The tire wear problem was not expected to be eliminated, so a quick change drive wheel design was required. Computer monitoring of the battery charge on the AWGV assured that a vehicle would be out of service only when a battery change was required. Limit switches on the exterior of the vehicle could be replaced with encapsulated proximity switches. The vehicle could use a rack and pinion drive mechanism for lifting and lowering pallets in and out of pallet receivers. The buffering shortfall could be corrected by adding pallet storage magazines to the FMS.

To justify the system and its increased production rates, major benefits of the system were outlined:

- Reduced direct, indirect, and inspection labor
- Elimination of setup
- Reduced rework and scrap material
- Lower capital equipment costs to meet increased production rates
- Reduced inventory
- Reduced part lead time
- Reduced material control costs
- Increased machine utilization
- Flexibility to adapt to changes in part mix and production rates.

The outcome of FMC management's review of the project was a directive to justify the system at lower production levels, which resulted in insufficient load on the system as configured. Further investigation was required to identify additional parts for the FMS application. Parts were selected from aluminum routing as well as machine shop operations. Simulations performed by the FMS vendors resulted in a mix of 17 parts requiring four machining centers.

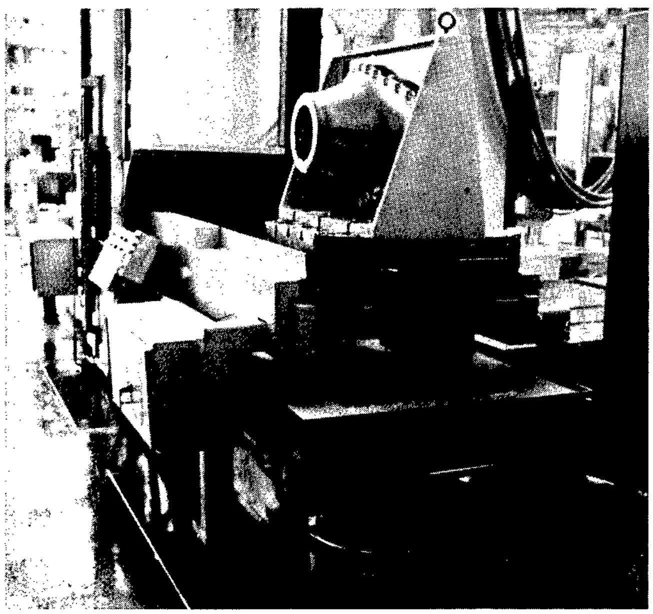


Figure 3

System Design

Having developed confidence in the FMS and its configuration, a vendor specification package was prepared which included the following:

- Part drawings and batch processing documentation
- Production rates
- Input data and results of Draper Labs simulations for the production rates specified
- Tooling, programming, and fixturing specifications
- Software requirements
- Machine and pallet shuttle specifications
- Layout and chip handling specifications
- System simulation requirements
- Material handling system specifications
- System acceptance criteria
- Terms and conditions of purchase.

Concurrent with the development of vendor proprosals, FMC addressed additional processing required to complete the selected parts. This additional processing meant that certain offline capabilities would be needed. For example, all parts would require some form of deburring. The deburring could easily be accomplished by providing a deburr bench or by conveying the parts to a nearby vibrating deburring machine. Some parts would necessitate the installation of steel inserts between the rough and finish machining operations. Another part required the assembly of a housing and cover prior to the finish machining operation.

Finally, certain parts called for drilling and tapping in attitudes that could not be accommodated by fixtures used in N/C part processing. Further simulations of the FMS by Draper Labs determined that offline drilling and tapping operations would not justify 5-axis capability. There was insufficient load to fully utilize the 5-axis machine, so that any additional cost would be high relative to the labor savings. Besides increasing the system's complexity, this particular configuration would preclude the backup of all capabilities in the system.

Manufacturing Cell Designed

The ongoing research led to the design of a manufacturing cell that consisted of part queues, deburr bench, oven, freezer, press, assembly table, drilling and tapping

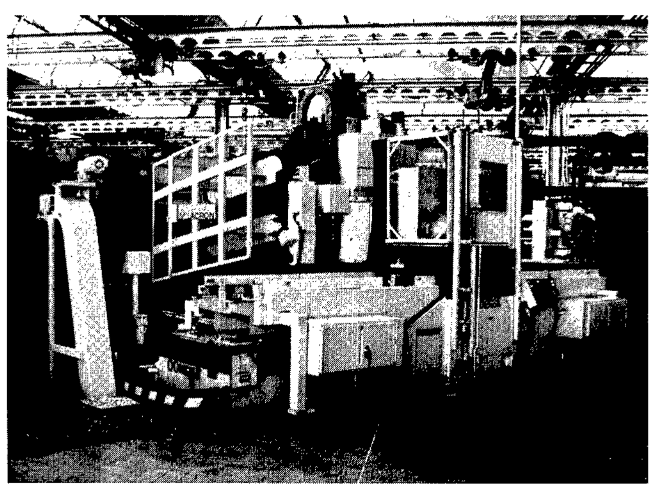


Figure 4

machine, and material handling devices. The cell, located in the part staging area of the FMS, enabled the parts to enter and exit the FMS from one location. Parts could then flow from the automated material handling system through the offline workstation with a minimum of handling and ensure that all processing was completed within the FMS.

The vendor proposals, including their system simulation results, provided further insight into the dynamics of the FMS. Previous simulations had not considered the impact of a coordinate measuring machine and an automated parts washer. These workstations tie up a pallet/fixture for a period of time and thus prevent it from being used elsewhere in the system. By adding these workstations, duplicate pallet/fixtures to maintain machine utilization and system throughput had to be added.

Because no consensus existed among FMS vendors regarding the type of material handling system to use, FMC faced a decision between the tow line conveyor or the automatic wire guided vehicle systems. Advantages and disadvantages of both alteratives were examined.

Reconfiguring the system from five to four machines was a significant change. The system cost could not be reduced at the same level as the benefits. Items in the FMS such as the material handling system, coordinate measuring machine, and the computer control system would be required whether there were four or five machines in the system. The four machine system was considered more complex. As more parts were added, the part deburring effort and the number of unique fixtures and tools in the system increased. Simultaneously, the tool storage capacity was reduced. This prevented running all the parts across any two machines, also reducing the level of backup and complicating the real time scheduling of the system in the event of machine failure.

As the first phase configuration of the FMS stabilizes, efforts to better understand its dynamics and eventual evolution continue. Further simulations should determine which parts need backup capability given the tool limitations of the system. Alternative modes of processing subsets of the selected parts in the system will be investigated to address potential raw part shortages. The objective will be to maximize system utilization while minimizing any additional fixturing and tooling required to support a higher throughput of subset parts.

It is expected that the FMS system will expand. Initally, this expansion would probably take the form of an additional horizontal machining center to increase production rates of parts selected for the FMS. Parts of rotation could be added to the system by incorporating an N/C chucker, a mini AS/RS, and machine loading equipment. Parts could then be batched to the turning machine and randomly processed to the horizontal machining centers. Tool limitations could be reduced by tool control and handling systems. Based on schedule and usage, tools would be transported by AWGV and inserted and removed from the machining centers automatically.

Flexibility A Key Factor

FMS technology has shown many advantages in low volume, high mix production applications. The evolution of the FMS project was affected most by factors outside the project study as overall division manufacturing plans continued to develop concurrently. These changes would have seriously impeded development of alternative machining approaches consisting of special purpose machines and head changers. Flexibility of the FMS in the face of change allowed adaptation and continuation of system design efforts. Even after the system design and justification effort had been completed, a major change in production rates and part mix was accomplished in a short period of time. FMC has therefore been able to realize many advantages of an FMS system even before authorization of project funding.

Proposed System

The proposed FMS system is shown in Figure 1. The operation plan is to incorporate redundant tooling so that critical parts can be processed on more than one machine to minimize the effect of machine downtime on system output and reconfiguration.

The coordinate measuring machine (4) is a gantry type unit incorporating a pallet delivery discharge mechanism and a computer control system. The configuration will allow palletized workpiece fixtures to be delivered to the inspection machine on a sampling basis for part inspection under FMS computer control. The coordinate measuring machine computer control will perform two major functions. First, it will communicate to the FMS computer receiving data on what parts have been delivered to the machine and subsequently what the inspection results are. Second, it will support the inspection machine function by

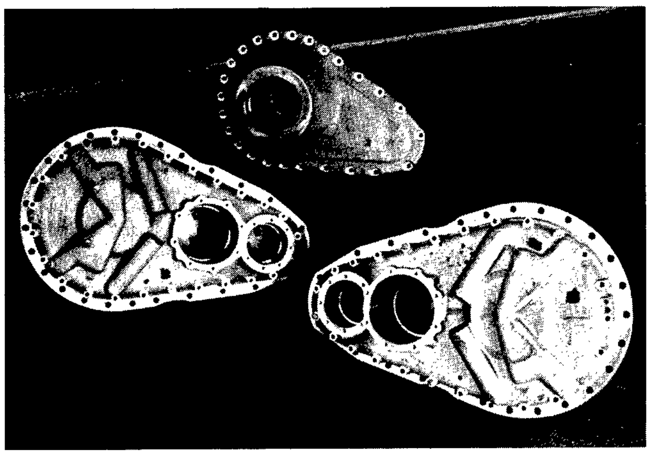


Figure 5

providing inspection part programming, part program storage, and direct computer control of the inspection machine.

Each load/unload station features a pallet receiver, pallet shuttle, and positioning mechanism. Palletized workpiece fixtures will be delivered and picked up by the material handling system. While in the load/unload station, the palletized workpiece fixture will be shuttled in and out of the positioner. The positioner will have two axes of rotation so that the palletized workpiece fixture can be tilted 90 degrees and rotated. Under the positioner will be a chip conveyor tied into a central collection system. This design will facilitate the loading/unloading of heavy parts and the removal of chips from the parts and fixture.

The pallet storage magazine (3) consists of a pallet delivery/discharge mechanism, a ten pallet storage magazine, and pallet service station. The pallet storage magazine will allow palletized workpiece fixtures to be placed in and out of storage by the material handling system under computer control. Two pallet storage magazines with a total storage capacity of twenty pallets are required since there will be more palletized workpiece fixtures than available workstations in the system. The pallet service station will provide the capability to remove a pallet/fixture from the system for checking, repair, or changing of fixtures.

The offline workstation (5) is connected to a load/unload station by a roller conveyor. The workstation incorporates into a cell equipment which performs operations that cannot be done on the machining centers. The operations are: deburring, isolated drilling and tapping, assembly/ disassembly, sawing, and the pressing of steel rings.

The material handling system consists of three AWGVs's, a control computer, a series of wires embedded in the floor, and support equipment. The AWGV is an unmanned battery powered unit which receives its commands from the radio frequency signals in the wires. A standalone computer controls the direction and location of travel of the AWGVs, while the FMS computer determines the workstations to be serviced. The support equipment consists of extra batteries, battery chargers, manual cart controls, frequency generator, area controllers, and battery carts required to operate and maintain the AWGVs.

The horizontal machining centers (2,7) are each equipped with a 20-horsepower spindle, a CNC control, an automatic tool changer, a 90 tool storage magazine, and an indexing rotary table. The capacity of the four tool storage magazines is greater than the minimum requirements for the selected part mix and provides flexibility to:

- Respond to changes in part processing methods which require additional tooling
- Add parts to the system

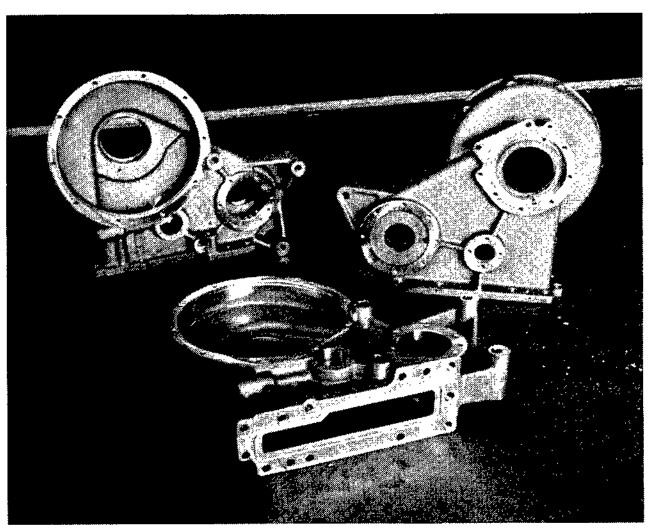


Figure 6

- Select part mixes with a greater number of tool requirements
- Process some parts across more than one machine.

Figure 2 shows a pallet and fixture carrying a part for transfer on a transport vehicle (Robocarrier), a computer controlled robot transporter guided by wires laid in the floor of the production facility. Figure 3 shows a Robocarrier removing a machined part from the horizontal machining center, and Figure 4 shows the horizontal machining center itself. Figures 5 and 6 are, respectively, of a final drive for the Bradley fighting vehicle which has been machined completely by automation equipment and a power takeoff of the Bradley fighting vehicle which also has been finish machined automatically.

The numbered items in Figure 1 relate to (1) the orient wash station (2) an automatic wire guided vehicle servicing a horizontal machining center, (3) pallet storage magazines, (4) a coordinate measuring machine, (5) an offline work station, (6) future automatic tool exchange equipment (outlined by dashed lines in the same layout as in the four central locations), (7) a future horizontal machining center, and (8) an automatic wire guided vehicle service area.

Computer Common Link

The common link among all of the hardware items previously described is the FMS computer. Computer control of complex machining systems requires sophisticated software to obtain high system utilization and to react to planned and unplanned events in the production environment. The functions residing in the FMS computer control system are:

- Traffic coordination
- Work order entry
- Staging
- Simulation
- System configuration
- Batch scheduling
- RJE
- Data distribution.

These software functions provide capabilities required to operate an FMS. Among these capabilities are:

- Remote distribution of N/C programs and data files to machine N/C tool controllers
- Maintenance of NC program libraries
- N/C part processing at remote facilities via telecommunication links
- Automated delivery of workpieces to work stations
- Management of pallet and fixture data
- Modeling of system activities to assess the impact of changes in production requirements
- Scheduling, preparation, and staging of work orders for workpiece entry into the system and control and monitoring of system resources
- Diagnostics for maintenance and troubleshooting of system facilities
- Recording of accounting data and formatting of management reports from the data
- Tracking and management of tools used within the system.

Growth and Change Planned

The FMS will be configured to allow expansion and incorporation of new technology. Space is provided within the FMS for a fifth horizontal machining center. Additional growth will be a possible adjacent to the coordinate measuring machine and pallet storage magazines. The layout of the machining centers will also allow future addition of automatic tool exchange equipment. This equipment would be part of a tool control and handling system with the following functions:

- Computer generation of tool requirements by machine based on part mix, schedule, and usage
- Preparation of tool kits by machine in the preset area
- Automatic loading of tool preset data in the N/C control
- Delivery of tools to the machine tool
- Exchange of tools for spent tools
- Return of spent tools to the preset area for reprocessing.

Transportation of tooling between the preset area and the machine tools would be accomplished under computer control utilizing the AWGV.

As one can see, the FMS was a well thought out and thoroughly conducted program—from the initial concept studied to the establishment of key inputs and variables. This project resulted in the evolution of a system configuration based on changing production requirements and system expansion considerations.

Brief Status Reports

Project 6350-2422, AMMRC. Inspect/ Meas Method for Sperical Surfaced Components. The fabrication of the test equipment was completed. The profile plates have been evaluated by an independent laboratory technique at ARRADCOM. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5019, CORADCOM. Laser-Cut Substrates for Microwave Tubes. Contract awarded to Northrop. A successful two-step high resolution etching process will be used to laser micromachine IBCFA anode circuit bed ceramic heat sink/mount/ insulator. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Proejct 5041, CORADCOM. Millimeter Wave Mixers and Arrays. Alpha Industry used computer controls to make MMW Schottky barrier mixer diodes that meet specs at 56, 94-120 GHZ, but not 140 GHZ. Impedence reduction of double ridged matching structures incorporated. Split block housing broached. For additional information, contact Al Feddeler, CORADCOM (201) 535-4062.

Project 5042, CORADCOM. Large Diameter Neodymium YAG Laser Crystal Boules. Litton Systems, Airtron Div., built a new station for growing larger 2 inch neodium doped YAG boules. Twelve rods were cut and tested and passed. thirty rods may be used in GVS-5 rangefinder. Demo was held in March. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 5109, CORADCOM. Precision Low-cost Surface Acoustic Wave Delay Lines-UHF Appli. TRW is optimizing fabrication and test processes for 403 and 506 MHZ UHF surface acoustic wave devices. Four mask sets were built, each with transducer pairs. Test fixtures were designed and semiautomatic assembly equipment bought. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3010, CORADCOM. Millimeter-Wave Sources for 60, 94, and 140 GHZ. Hughes impact oscillators showed no effect when exposed to 10,000 RAD/SI. Pilot production of MMW impatts is completed. Modulator timing and pulseforming problems overcome. Resistor heating caused circuit to be unstable. Solution: mount external to can. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3011, CORADCOM. Indium-Phosphide gunn Devices. Varian Associates is mechanizing the thinned integral heat sink process to get 10 micrometer device structures. Metallization and alloying steps were combined. SEM inspection and package etching were eliminated. In-process measurements aid uniformity. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3026, CORADCOM. High Pressure Oxide IC Process. ET & D Labs ordered a major revision of the furnace to reduce convection of hot gas to cold vessel walls. Now in use is a closed bell-jar type container around the furnace elements. New parts were made and fitted into the chamber. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3031, CORADCOM. 10.6 UM Co-2 TEA Lasers. Raytheon established production methods for forming, sealing, and processing ceramic laser housings. Worked on electrodes and mirrors for alignment and parallelism. Optimized gas mixture. Need polarizing element in laser cavity and this led to cost growth. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3501, CORADCOM. Third Generation Photocathode on Fiber Optic Faceplate. ITT has had trouble growing gallium-arsenide layers on gallium-arsenide wafers to make 3rd generation photocathodes. ITT developed a multi-frequency scan test to check layer thickness. NV + EDL + ITT think they have the uniformity problem solved. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 3505, CORADCOM. High Contrast CRT Phosphor Deposition and Sealing. Technical transfer from Lockheed to Hughes enabled Hughes to fabricate faceplates. The faceplate has a 3-fold increase in red luminance. Reproducibility of faceplates is high. Sputter target was achieved and is satisfactory. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 7963, ARRCOM. Group Technology for Fire Control Parts and Assemblies. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 5002, TACOM. Fabricating Torsion Springs From High Strength Steels. Preliminary analysis of fatigue life shows E4350 steel is outperforming E4150. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 5005, TACOM. Computer Aided Design for Cold Forged Gears (Phase I). The data section of the computer program that handles both spar and helicar gear geometries has been completed. The drawing routines were modified. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 5014, TACOM. Foundry Casting Processes Using Fluid Flow and Thermal Analysis. University of Pittsburg was awarded a contract to expand the geometric capabilities of the current system. Presentations on the results have been made to weapon system designers and foundry representatives. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 1018, MICOM. Improved Manufacturing Processes for Dry Tuned Accelerometers (CAM). This project is complete. An end of contract demonstration was held March 29. The technical report is being prepared. Final testing is under way. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5147, CORADCOM. High Resistivity Polycrystalline Silicon. Hemlock Semicon Corporation modified the trichlorosilane reactor for production of 72 MM diameter detector grade polysilicon. They made 330 kilograms of polysilicon. Vapo-phase purification system is in progress. This gives us a domestic source of polysilicon. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 6350-2200, AMMRC. Automatic Identification, Sizing, & Counting of Particulate Contamination. The system is operational and sample preparation problems have been solved. New software incorporating recently developed algorithms for more precise measurements which are more user friendly have been procured. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2205, AMMRC. Holographic Inspection of Rotary Forged Preforms. Phase I System is electronically and mechanically complete and meets the technical criteria. For final acceptance, a demonstration of the operational requirements and certain computer software was conducted in December, 1982. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2418, AMMRC. Half Life of Tritium Lamps. This project has been delayed due to the late receipt of hardware samples and test results. The data anlysis was not completed until January 1983. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2419, AMMRC. Fire Control Components Automatic Inspection. This project has been completed. The OTF criteria developed by this project cannot be recommended for resolution measurement for inspection of image quality of visual optical systems. This criteria can lead to false rejections of good optics. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2420, AMMRC. Optical and Dig Standards and Measuring System. NBS has completed the measuring equipment. A number of standards have been assessed. The results appear promising. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5010, CORADCOM. Bonded Grid Electron Gun. Varian completed computer analysis of the boron nitride electron guns bonded grid structure. Laser milling equipment was ordered. Techniques for production bonding the grid to the cathode are under evaluation. Guns will operate at less than 1000 volts. For additional information, contact Al Feddeler, CORADCOM, (201) 535-4062.

Project 5000, CORADCOM. Production of Hot Forging of Alkali Halide Lenses. Highly successful processes for pressing IR lenses to shape have been developed by Honeywell. The water impermeable coating effort has not been successful, so implementation of the inexpensive KBR lens is not foreseen. Test method is very successful. For additional information, contact al Feddeler, coradcom, (201) 535-4062.

Project 6350-2613, AMMRC. Inflow air Bleed Test, LTC-712 Engine. The project was re-evaluated regarding progress to date, objective and funds. It was determined what funding would be required to complete the project. As a result of this project re-evaluation, AMMRC funded the effort. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 6350-2614, AMMRC. Temperature Compensated Voltage Cont Crystal Oscillator Test Methodology. The Government has accepted the final revised methodology and test procedure for evaluting the frequency stability of temperature compensated voltage controlled crystal oscillators. The contractor started testing crystal oscillator. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 1907, ARRADCOM. Automated Gaging for Medium Caliber Projectile Bodies (CAM). The work effort centered on the completion of the prototype gaging system to characterize the features of the forward fuse mating threads. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 7201, ARRADCOM. Artillery Weapon Firing Test Simulator. This project is complete. A final report is being prepared. For additional information, contact Dennis Dunlap, ARRADCOM, (309) 794-3270.

Project 7580, ARRCOM. Pilot Automated Shop Loading and Control System-CAM. All modules are operational and being used. Work is in process to plan and schedule critical components for the other major items. The project is complete. for additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 5071, TECOM. Smoke Obscuration Test Procedures. The technical approach for the measurement of smoke obscuration/attenuation was established. In addition, the requirement necessary to acquire equipment and instrumentation was also established. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 5071-60, TECOM. Receiver Operating Characteristics Measurements. The first phase of the ROC Methodology Investigation has been completed which included technical review, instrumentation requirements, and procedures. The investigation is in suspension until the equipment is purchased through the instrumentation acquisition. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 0900, ARRADCOM. Automated Multiple Filter Life Tester. Two techniques for dispersing a chemical agent were developed. One utilized a piezoelectric crystal to vaporize the agent. The other used a thermal resistor to disperse the agent. A bellofram diaphragm pump was developed as a simulated breathing device. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 0905, ARRADCOM. Manufacture of Impregnated Charcoal-Whetlerite. The scope of work for contract effort was completed. The procurement request package has been submitted. For additional information, contact Donald Fischer, ARRADCOM (201) 724-5957.

Project 0913, ARRADCOM. Spin Coating of Decontamination Agent Containers. Contract awarded. Technology and engineering evaluations conducted. Application techniques are being evaluated. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 1335, ARRADCOM. Manufacturing Techniques for New Protective Mask. Pilot production line installed and production of individual components under way. Prototypes of alternate faceblank material being fabricated. Top is complete. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 1060, MICOM. Electrical Test and Screening of Chips. Teledyne tac is identifying chip testing methodologies. Applicability of baseline system is being evaluated. Process model evaluates temperature of a silicon chip as a function of time and location. Data is being collected on air flow wear chip. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1072, MICOM. Mulitple High Reliability/Low Volume LSI Manufacturing (CAM). Work has been completed on the industry survey, processing plan, photoresist processes, mask inventory handling, wafer etching, patterning, multisource doping, diffusion, chemical vapor deposition and process CAM, for making ICS. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3532, MERADCOM. Molten Salt Lithium-Chloride Battery. Prototype cells built for a 30 cell 12KWH 36V battery continue to show excellent life cycle characteristics. Average of 370 cyces thus far. Selection of 30 cells for MERADCOM BATTERY COMPLETED. Cell data indicate excellent chance of achieving 300 CYS. For additional information, contact Emil York, MERADCOM, (703) 664-5872.

Project 1295, ARRADCOM. Modernization of Charcoal Filter Test Equipment. The design of the containment chamber was finalized and the Level 1 drawings completed. A modular panel type assembly was proposed to facilitate shipment and reconstruction. For additional information, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 3592, MERADCOM. Improved Graphite Reinforcement. Optimization of the oxidation and carbonization processes is complete. Tensile properties were shown insensitive to oxygen content of the fiber, but they were improved by higher carbonization rates. For additional information, contact Emil York MERADCOM (703) 664-5872.

Project 3708, MERADCOM. Coated Fabric Collapsible Fuel Tank Program—Circular Seamline. Seamless fabrics coated at contractors facilities Coating operation accomplished with difficulty. Coated sleeves fabricated into tanks. Mounting of patches for hardware and sealing of end seams proceeded slowly but satisfactorily. Testing begun. For additional information, contact Emil York, MERADCOM, (703) 664-5872.

Project 3709, MERADCOM. Continuous Length Fuel Hose. All work has been terminated. Continuous length fuel hose is now available commercially at considerably lower prices than previously used hosing. A final technical report is being prepared. For additional information, contact Emil York, MERADCOM (703) 664-5872.

Project 7605, ARRCOM. Chemically Bonded Sand For Close Tolerance Casting. The small core sand system was checked out and the layout was improved. A floor mounted crane was added for convenience to the workers. Plans for large molding system complete. Some green sand equipment dismantled and/or removed. Most new equipment received. Pits almost complete for new shakeout and reclaimer units for chemically bonded sand. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7707, ARRCOM. Automated Process Control for Machining. Software for an interactive computer procedure is being developed to aid the selection of machining conditions. Needs exist for NC programming, industrial engineering, methods and standards, and various levels of management. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

7724, ARRADCOM. Group Technology of Weapon Systems (CAM). A computer aided process planning program was developed and tested. The software is currently being revised. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7730, ARRCOM. Manufacture of Split Ring Breech Seals. Modifications to kinking unit continue. Technical proposals for ring splitting equipment were evaluated and accepted. Step 2 of 2-step procurement action is under way. Construction of a polishing fixture is in process. Preliminary testing of the kinking unit revealed several weak areas in the machine construction. Modifications are under way to correct these areas. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 3749, TACOM. Hydraulic Rotory Actuators. Original actuators tested. Four additional actuators were completed and tested. Producibility plan and critical item specs have been delivered. Top is complete pending an ECP to make minor modifications. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 6350-2450, AMMRC. Gun Steel Adhesion Chromium Coating Measurement. The ultracentrifugal adhesion test assembly was recovered, inventoried for completeness of the various subassemblies, and delivered for modification. Delivery of the completed system is scheduled for October 1983. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 4264, TACOM. Track Inserts and Filters for Track Rubber Pads. Torsion test machine now completed and installed. Qualification testing is under way. A final report is being prepared. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 4575, TACOM. Laser Welding Techniques for Military Vehicles. Production mockup using military turret ring casting to inner turret wall completed. Ballistic test plates prepared. Testing preformed and preliminary results positive. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 1042, MICOM. Production of Composite Radome Structures. Efforts to produce the full-scale radome are under way. Part design and tooling design and fabrication are nearly complete. In-process quality control procedures are being evaluated. Option on contract has been extended (two layer radome). For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1050, MICOM. Low Cost Braided Rocket Motor Components. The full scale motor concept and reproducibility demonstrations have been accomplished. Delivery of production components for test firing is under way. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 6350-2616, AMMRC. Automated Software Aids for Testing Requirements. The demonstration/evaluation was performed and proved the functional characteristics of the tool. Delivery and training for the software requirements analyzer for tes tool has been accomplished. Installation in Government facility is in progress. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 2858, AMMRC. Stress Reading Transducer for Large Composite Components. Instrumentation which can emit light at a specific wavelength and intensity and a power meter which can measure transmitted light, either linear or logarithmic scale, has been received and operated successfully. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 3411, MICOM. Non-Planar Printed Circuit Boards. Antenna machining of the datum control features is complete. Sample radiation patterns have been taken. Circuit board fabrication of additional cylindrical boards was started. An alternative configuration is being discussed. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 6057-03, TACOM. Automated Metallizing. General Dynamics Land Systems Division submitted a revised quotation. Government audit was completed and the TACOM pricing review was completed. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 8192, AVRADCOM. Turbine Engine Productivity Improvement. This phase completed in May, 1982. This is the first of a three phase effort. 3D model acquired. Redesigned balance room installed. Make or buy analysis completed. Final status report received. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 5019, TACOM. Low Maintenance Storage Battery. Prototype batteries from contractor have been delivered to TACOM for laboratory and field tests. Test programs and scheduling for laboratory and field tests have been completed. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 2418, AMMRC. Half Life of Tritium Lamps. A quantity of tritium lamps were produced. Half of the lamps were subjected to an accelerated aging test. The balance of lamps were maintained as a control. Results from the accelerated test are being analyzed to determine brightness decay patterns. Final status report received. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 2419, AMMRC. Fire Control Components Automatic Inspection. The OTF measurements do not correlate with standard resolution tests; this creates the potential problem of rejecting optical instruments that are acceptable for use in the field. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5053, TACOM. Fabrication Techniques for High Strength Structural Ceramics. A sole source contract was awarded to Cummins Engine Co., and the role of AMMRC was organized. Project work was initiated. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 7342, AVRADCOM. Pultrusion of Honeycomb Sandwich Structures. The stop work order on the contract is still in effect. The contractor has submitted a revised SOW and cost summary for completing Phase 1. Phase 2 has been cancelled. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 1121, MICOM. Missile Manufacturing Productivity Improvement Program. The options for this Phase II portion will not be exercised until the Phase I portion is completed at Rockwell and Martin. Follow on actions were delayed by the HELLFIRE office pending implementation of dual source procurement strategy. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5071-37, TECOM. Rollover Test of Military Vehicles. The first phase of this investigation was completed by Varigas Research Incorporated. A report was completed. Five types of Army vehicles were identified as having high rollover history when involved in emergency maneuvers. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 2631, AMMRC. Critical Electromagnetic Inspection Problems Within The Army. The eddy current instrumentation for determination of case depth was checked out. The evaluation of equipment to perform case depth was started. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 2639, AMMRC. Roadwheel Seal Test Machine. The design work has been completed. Procurement of required purchased items is in progress. In-house fabrication of the machine is in process. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5071-43, TECOM. Test Automation. Three testing automation procedures were completed. Two sets of processing requirements were established. Advanced communications testing procedures for evaluation of digital system were analyzed. Automated analysis of EMI data were identified. Final status report received. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 3056, CECOM. Electroluminescent Numeric Modules. Rockwell-Collins is developing processes for depositing thin films, attaching drive circuits, and handling masks automatically for electroluminescent displays. IC chip bonding and hermetic sealing done. A line to build 10,000 units/mo. is needed. For additional information, contact Martin Ides, CECOM, (201) 532-5779.

Project 1126, MICOM. Wound Elastomer Insulator Process. Preliminary physical and process properties testing on various insulator formulations were completed by Hercules. Microwave co-cure screening evaluated insulators which were wound onto a metal mandrel and then overwrapped with Kevlar/epoxy cases. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3083, CECOM. MM Wave Communications Front End Module (CFEM). A firm will establish processes to build millimeter wave front end modules for 36-38 GHZ operation. Includes diode source, bite coupler, power attenuator, bandpass filter, mixer, oscillator source, and IF preamplifier. For command post radio. For additional information, contact Martin Ides, CECOM (201) 532-5779.

Project 3218, MICOM. Reduce the Finishing Cost of Fused Silica Radomes. The matched dye mold was developed for producing Patriot sized radome blanks. Castings were fired and shrinkage was minimal and within tolerances. This project is complete except for the final report which is being prepared. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 7382, AVRADCOM. Low Cost Composite Main Rotor Blade for the UH-60A. Current outer mold tooling will be used to mold the blades. Fabrication hardware is being constructed. Fabrication of the process development specimens (short spar sections) is nearing completion. Alternate approach of integral winding in process. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 5090. TACOM. Improved and Cost Effective Machining Technology (Phase III). Data for a cross section of work performed by the contractor has been reviewed and analyzed. Economic analyses are being performed to identify cost effective machining conditions. Drilling tests have been performed to evaluate various point geometries. Tests are being developed to evaluate special surface treatments on HSS tools. A cutter design is being developed for the machining or counterbores in L605 split ring shroud. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 3057, CECOM. High Stability Vibration Resistant Quartz Crystals. Frequency Electronics Inc. set up X-ray, angle correction procedures, metallization, bonding, and flatpac packaging methods. Have cleaning, gold plating for frequency control, vacuum bake and sealing stations. A carousel accommodates 50 crystal holders. For additional information, contact Martin Ides, CECOM, (201) 532-5779.

Project 3139, MICOM. Millimeter Seekers for Terminal Homing (TH). Testing of prototype unit is complete. Pilot line fabrication and analysis is complete. Five production units have been fabricated. Industry demo is completed. Work is continuing on motion picture and final report. Cost for MMW front end is dropping. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5067, TACOM. Plastic Battery Box. All field testing results have been evaluated. Final technical report forwarded to printing shop and awaiting delivery for distribution. TDP changes delayed because additional durability field testing required. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 7371, AVRADCOM. Integrated Blade Inspection System (IBIS). A preprototype XIM has been developed which is being used to establish a baseline for recognizing and analyzing flaws. Software for blade analysis has started. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 2814, AMMRC. GC/Mass Spectroscopy. Two methods were developed for determining the amount of benzanthrone in various dyes. A final technical report is being prepared. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5071-67, TECOM. Interoperability Test Methodology. A preliminary specification for an automated test driver was produced. A technical requirement for an automated test driver system electronic semitrailer was also generated. The contractor is currently defining ME. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 2815, AMMRC. Cannon Tube Automated Chrome Plate Thickness Measurement. A set check was designed, manufactured, and delivered. A contract has been written to develop a system interface with the 8-in. gun tube inspection system. Fixture design for same has been initiated. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 3073, CECOM. Tactical Graphics Display Panel. GTE established automated deposition process for thin film electroluminescent layers on 10" x 12" matrix panels. Cost will be cut by optimum cleaning, handling, and sealing techniques. Panels have 640 columns and 512 rows. Hybrid drivers to be used. For

additional information, contact Martin Ides, CECOM, (201) 532-5779.

Project 2817, AMMRC. Fiber Optic Cable Assemblies Test Criteria Development. A suggestion from CECOM concerning the possible duplication was evaluated. After the review it was decided to revise the statement of work to remove the duplication. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 3142, MICOM. Production Methods for Low Cost Paper Motor Components. All technical work is complete. Draft technical report circulated. Final technical report and final 301 report will be distributed during next reporting period. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 2820, AMMRC. Integrated Focal Plan Module Test Station. FPA and CCD test parameters were defined and a data base was designed and structured. Additionally, software packages that will be used to test CCE and FPA were designed. Final status report received. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 7376, AVRADCOM. Automated Inspection and Precision Grinding of SB Gears. Equipment has been installed and debugged. Baseline master gears were comparison checked on Zeiss machine and the Gleason contact pattern checker. Analysis of comparison under way. Drawings released and operation sheets written for specimen gear and pinion. Final status report received. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 2828, AMMRC. Composite Motor Cases Acoustic Emission Proof Test Damage Evaluation. A sensor, patterned after an NBS design, was fabricated having a small conical, piezoelectric element whose point contacts the specimen. Tests with this pulse type sensor demonstrated that its response agrees identically with the theory. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5085, TACOM. Production Techniques for Fabrication of Turbine Recuperator. The two laser system was assembled by the subcontractor. After a successful system and process demo, acceptance testing was performed. System now on line at AVCO Lycoming. Awaiting final 301 and technical report. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 2829, AMMRC. Detector Dewar Microphics Produces Test Set and Procedures. The vibrational equipment for simulating common module cooler vibrations requirements have been defined. Work is under way to design the interface fixture for the unit under test. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5071-76, TECOM. Gamma Dosimetry Improvement and Modernization Program. A major portion of the gamma dosimetry processed during FY82 was in production support of MI Abrams and Bradley Fighting Vehicle Systems. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 5091, TACOM. Heavy Aluminum Plate Fabrication (Phase I). Aluminum armor plate and welding electrodes received. Holding fixtures and weld joints designed. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 2977, AMMRC. Image Intensifier System Veiling Glare Tester. The contract package was submitted to procurement. The contract was awarded in June, 1983. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5071-95, TECOM. Rapid Evaluation of Environmental Hazards. Work continued on the preparation of a comprehensive report dealing with rate and persistence of GB and VX in soil, water, and vegetation. Several crops of beans were grown and harvested in this time period. Extracts were made from various plants and spiked with QL. For additional information, contact N. Pentz, TECOM, (301) 278-2375.

Project 2235, AMMRC. Acoustic Emission Weld Monitor. The contract for Phase 3 was awarded to General American Research Division in September, 1982. A clarification meeting was held with the contractor regarding the masking study aimed at reducing or eliminating false signals during grinding. Final status report received. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 9898, CECOM. Ruggedized Tactical Fiber Optic Cables. ITT solved many production process problems. There were three revisions of the confirmatory test report before acceptance. All optical fiber required for pilot run has been produced and tested. Pilot production turn-on of cables given in January, 1983. For additional information, contact Martin Ides, CECOM, (201) 532-5779.

Project 2245, AMMRC. Ceramic Material NDT Evaluation Techniques. Work on eddy current techniques is continuing to evaluate C-scan for ceramic materials. An ultrasonic contour following capability will be utilized to inspect actual components. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5064, TACOM. Lightweight Saddle Tank (Phase III). Durability testing is in progress at the Tropic Test Center, YPG, and cold region

test site. Another tank shipped to APG for testing. Preparations are under way for testing a tank on an M939 vehicle at Houghton, MI. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 2804, AMMRC. Binary Munitions Mechanical Rupture Properties Test. The prototype tester design has essentially been finalized. The fabrication of the tester is under way. The contractual effort is on schedule. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 2811, AMMRC. M42-M46 Magnetic Flux Leakage Inspection. The MFL inspection system and design and standards have been reviewed. The fabrication of the system is under way. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 2813, AMMRC. Adaption Kit Function Embedded Microprocessor Testing. The requirement definition for the module has been initiated. These requirements are based on all P11 SAFS and its subcomponents. An automatic test system capability for the SAFS, SACA, WPCA, and Optical Link is being developed. For additional information, contact David Seitz, AMMRC, (617) 923-5527.

Project 5071-59, TECOM. Solar Powered Instrumentation Van. The heater/cooler system has been redesigned to operate from solar PWR. The wiring of the signal conditioning system and microcomputer main chassis was completed. The heater/cooler system has been checked out using auxiliary pumps. Final status report received. For additional information, contact N. Pentz, TECOM, (310) 278-2375.

Project 5057-13, TACOM. Laser Cutting. General Dynamics submitted revised quote for proposal originally submitted by Chrysler. Government audit completed and TACOM pricing review completed. Final status report received. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 3423, MICOM. Low Cost/High Performance Carbon-Carbon Nozzles. The interim technical report has been completed and is being distributed. The effort will continue. Candidate selection and concept demonstration have been completed. Concept refinement and reproducibility testing have been initiated. Plans for a full scale motor nozzle demonstration are under way. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 6057-04, TACOM. Thermal Cutting of Tracked Combat Vehicle Parts. Contract awarded to General Dynamics. Parameters have been established for single torch straight and bevel cuts. A triple torch setup is currently being investigated. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 3441, MICOM. Application of High Energy Laser Manufacturing Processes. All work has been accomplished. Awaiting the final technical report. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 7963, ARRCOM. Group Technology for Fire Control Parts and Assemblies. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

Project 7341, AVRADCOM. Structural Composites Fabrication Guide. Data gathering is continuing. A demonstration of composite structure fabrication techniques was presented at AVRADCOM. For additional information, contact Gerald Gorline, AVRADCOM, (314) 263-1625.

Project 5075, TACOM. Military Elastomers for Track Vehicles (Phase II). T-152 track pads have been made and tested. T-142 track pads also have been manufactured and are being tested. Procurement actions and testing arrangements are being made for the T-156 (Abrams M1) track pads. Track rubber spec will be written. T-142 track pads containing Kevlar fibers have been manufactured. Track rubber specification will be written to encompass improvements. Spin-offs for other elastomer items will be realized. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

Project 4062 06, ARRADCOM. Prototype Production Tooling. The contract was awarded to Innova, Inc. Also, the prototype tooling design work will be interfaced to the recent tooling improvements made at EDS Corporation to insure proper incorporation into effort. For additional inforation, contact Donald Fischer, ARRADCOM, (201) 724-5957.

Project 1108, MICOM. RF and Laser Hardening of Missile Domes. Battelle worked on deposition of a thin conductive nickel coating on a COPPERHEAD nosecone. Nickel was electroplated on the threaded area. A fine mesh grid was bonded to the coated nosecones. This protects the internal circuitry from RF energy. For additional information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5082, TACOM. Flexible Machining System, Pilot Line for TCV Components. This project is complete. A final technical report is being prepared. FMS feasibility studies are currently being conducted at four different installations. For additional information, contact Dave Pyrce, TACOM, (313) 574-6467.

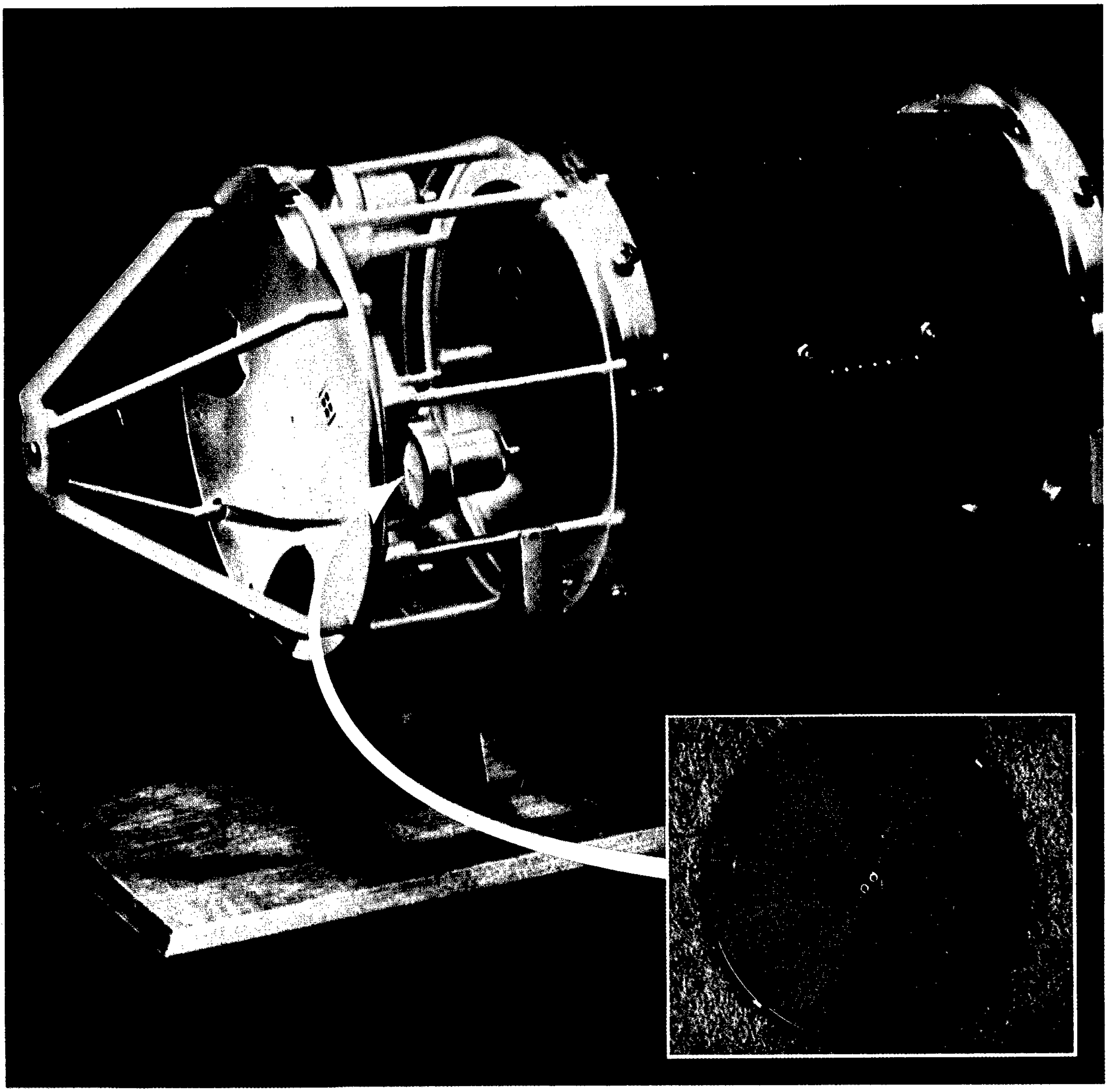
Project 8004, ARRCOM. Co-Deposition of Solid Lubricants During Anodizing. The technical report is in final draft and should be published in August, 1983. Procedures were developed and process parameters were optimized for a hardcoat anodizing process for the co-deposition of lubricious particles during hardcoat anodizing of aluminum. For additional information, contact Dennis Dunlap, ARRCOM, (309) 794-3270.

US Army

ManTech Journal

Implementing New Technologies

Volume 9/Number 1/1984



US Army
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Contents

About the Cover

An inexpensive non-planar printed circuit board component for radar guided missiles is shown in this cover photograph. Developed by General Dynamics (Pomona) for the U.S. Army Missile Command, the objective of achieving a new fabrication technique for a highly accurate antenna configuration was met by use of a highly stable injection molded polymer reflector. The reflective surface is accurate to 1/100 of a wavelength, despite the unit's inexpensive manufacture.

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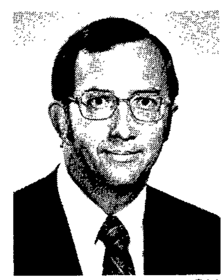
Comments by the Editor


RAYMOND L. FARROW

The coming year promises to focus attention on our efforts in manufacturing technology as never before, as efficiency in production becomes an ever more important factor toward meeting our objectives in the production of military items. The current adjustments in administration of the DOD manufacturing technology program will have numerous impacts on the services' projects and undoubtedly will give rise to some degree of uncertainty for some individual projects, but in the long term our efforts will receive many benefits from the increased attention given by those responsible in government, and, also, by the public. One of the more significant of these items that soon will be in operation is the proposed Manufacturing Technology Information Analysis Center, which will be discussed in more detail in a later issue of the U.S. Army ManTech Journal.

This issue of the Journal features some highly significant developments that have resulted from successful Army mantech projects. Non-planar PC board fabrication fits nicely into that category, as described in our first lead article and illustrated on our front cover. The project goal to produce an inexpensive non-planar PC board component for airborne radar guidance of missiles met with remarkable success. The ultimate device developed from the program is a model of efficiency—a self-contained transmitter/receiver which operates with extreme accuracy under tough environments, providing the functional capability required. The cost of the item was kept down thru a well conceived and managed project, and is a prime example of what Army mantech projects can achieve.

Our second featured article on compliant air bearing gyros also represents an outstanding mantech achievement. A 24 percent reduction in projected production cost of the component was all the more remarkable, since a sharp change of direction in the approach of the program was required as new data were developed. Insurmountable technical difficulties mandating the change nevertheless did not prevent the successful development of new manufacturing techniques that brought significant cost reductions. Also, the technical credibility of the item's operational performance was firmly established.

The production rate of infrared detectors of laser energy for laser warning receivers was increased through the successful completion of an Army project that developed a manufacturing technology which would produce the components at a rate of 50 per 40-hour week. In the course of this program, a determination was required as to which type of device structure would be most feasible for a higher production rate. The mesa type that ultimately was selected experienced a pilot run on a new facility designed expressly for this increased production rate, providing the feasibility of the technology under a production environment. Original production rate goals were exceeded by a factor of 6.5, attaining an overall yield of 32.7 percent.

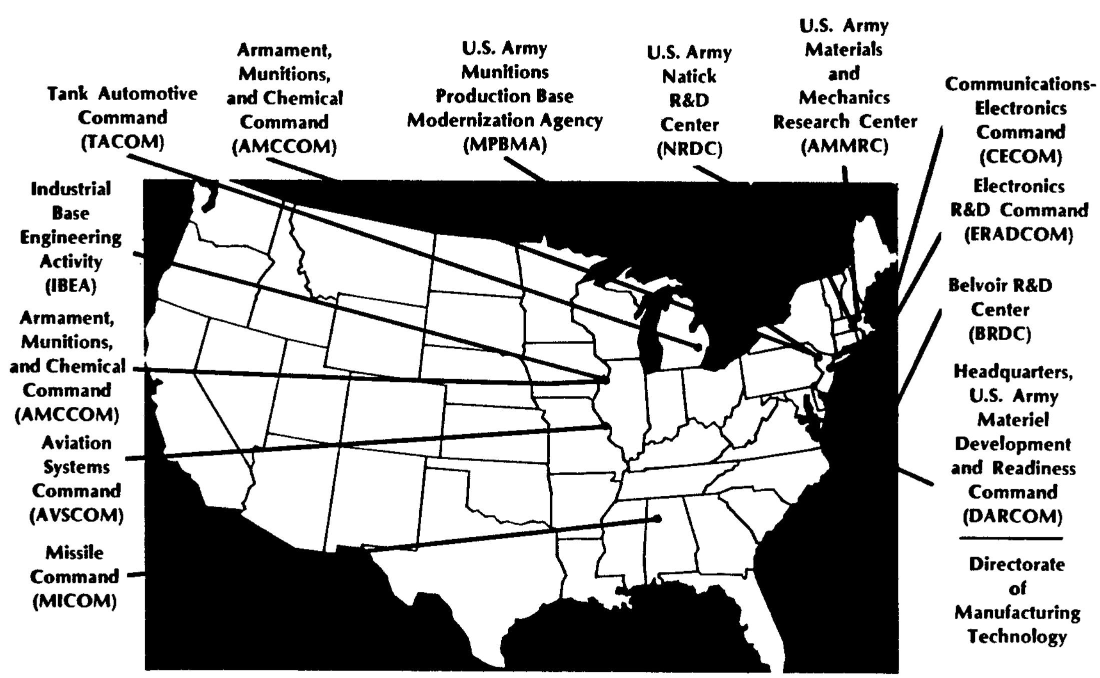
The excessive physical size and sheer complexity of large scale hybrid microelectronic items has caused severe manufacturing problems, but this was dramatically improved by the Army mantech project described on page 25 of this issue. The high frequency of rework that always has been required by the fabrication of such complex items was sharply reduced as a result

of this program. A new technology featuring the use of bumped tape automatically bonded beams made possible a fabrication technique that led to the successful attainment of project goals.

Ultrasonic activation of cutting tools met with considerable success in another Army mantech project that enabled the manufacturer to increase removal rates of machined items as much as 700 percent on materials that historically have presented difficult machining problems. With the ultrasonic assist, not only were metal removal rates increased, but tool wear and breakage were also reduced. This remarkable development will have a strong impact in years to come in projects where designers might otherwise have been reticent to specify a material that would have had the required performance characteristics, but which would present costly fabrication problems.

Six pages of brief status reports on ongoing Army mantech projects present a summary of efforts being undertaken by the major Army commodity commands. Each of these briefs lists the name and telephone number of the point of contact for that particular topic, so that readers can simply call him and obtain more complete information about the new technology as it is being developed. This custom has brought a lively exchange of information among industry and service personnel charged with improving our production capability.

DARCOM Manufacturing Methods and Technology Community



New Technique Accurate, Inexpensive

Non-Planar PC Board Fabrication Meets Specs

ROBERT L. BROWN is a General Engineer at the U.S. Army Missile Command in Huntsville, Alabama. His current projects involve creative direction of contractor engineers on projects such as the fully additive manufacture of printed wiring boards (Hughes), ultraviolet curing of conformal coatings for PC boards (Hughes), product cleanliness techniques for PC boards (Martin-Marietta), laser scan testing of PC boards (Chrysler), rigidflex assemblies (McDonnell-Douglas), and insertion of nonaxial lead devices in locaserts (Martin-Marietta), a recent approved success. A Registered Professional Engineer in Alabama and holder of a B.S. in Metallurgy (1958) from Alabama University, Mr. Brown holds six patents and is author of fifteen technical briefs which NASA rates as equivalencies to patents. He was the first recipient of the NASA "Noteworthy Contribution" award in 1970 for his many contributions to their technical utilization program, and patented several inventions that were used in production.

Formidable dimensional specifications were exceeded and a new manufacturing technology brought additional cost savings from an MM&T project recently completed for the U.S. Army Missile Command. Conducted by the Pomona Division of General Dynamics, the project goal was to produce an inexpensive non-planar printed circuit board component for radar guided missiles. The device was designed to be a self-contained transmitter/receiver to fit into the nose of a missile and operate under severe g-loads, providing extremely accurate and reliable targeting.

The objectives of the project concept were to develop new manufacturing technology for the fabrication of an antenna configuration that would provide accurate missile guidance, yet offer relatively low cost. The key to achievement of this goal was the development of a highly stable injection molded polymer reflector with a reflective surface accurate to 1/100 of a wavelength and additively plated to a minimum of .001 inch.

Two Tasks Undertaken

The effort encompassed two tasks: Task I addressed the manufacturing methods and applied technologies to produce a cassegrain antenna system designed to operate at 94 GHz. The antenna configuration analysis was completed and material selection criteria established. Design criteria and measured data were developed on three versions of broad-band spiral antennas.

The additive plating of the reflective surfaces was considered, as was the pattern generation of the subreflector grid. Test results also showed successful generation of the subreflector grid pattern to the required dimensions.

Task 2 addressed the manufacturing methods and technology required to produce an eight-layer cylindrical circuit board.

Material selection criteria were established, as were the requirements and technique of pattern generation and alignment. The forming process and related tooling were selected and the semi-additive process for installing plated-through holes was developed, as were data showing plated-through hole integrity and circuit continuity.

The work was performed by the Advanced Manufacturing Technology Department of the Pomona Division of General Dynamics Corporation under the technical cognizance of the United States Army Missile Command, Redstone Arsenal, Alabama.

NOTE: This manufacturing technology project that was conducted by General Dynamics' Pomona Division was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Robert Brown, (205) 876-5321.

The antenna system was comprised of a parabolic main reflector approximately 6 inches in diameter, a hyperbolic subreflector, a four port feed, and four 1-inch-diameter broad band spiral antennas with related cavity backing and feed connections. Materials, processes, and manufacturing technology required to produce an 8 layer, multilayer cylindrically shaped circuit board assembly having a minimum inside diameter of 5 inches were also determined.

Antenna Design Features

Discrete 1-inch diameter spirals were formed on the surface of the primary antenna dish sufficiently close to the edge as to be unobstructed by the subreflector. Each spiral was loaded with a cavity for operation in the 2.75 to 18 GHz range.

The subreflector had a curvature designed to feed the incoming radiation into the 4-port feed at the center of the primary reflector with minimum aperture blockage. Both the primary and secondary reflectors had a curvature that replicates the calculated curve to approximately 1/100 of a wavelength and were free from defects.

The secondary mirror had its 1-mil-thick reflecting surface divided into a grid of reflecting metal squares. Each square was one quarter of a wavelength on a side for a frequency of 94 GHz. The tolerance on the squares was about .001 inch, with a spacing of approximately .003 inch between edges of adjacent squares. The entire antenna assembly was mounted to an aluminum ring to simulate the forward end of a 6-inch diameter missile and was of a quality to serve as a bench test prototype.

The antenna configuration described is shown in Figure 1. The analysis of the antenna geometry is as follows:

D_M	=	Diameter of main Reflector
D_S	=	Diameter of subreflector
RFP	=	Real Focal Point
VFP	=	Virtual Focal Point
Θ_R	=	Angle (see Figure 1)
Θ_V	=	Angle (see Figure 1)
F_c	=	Distance from RFP to VFP
F_m	=	Distance from Dm (apex) to VFP
L_v	=	Distance from Ds (apex) to VFP

A computer program was formulated to perform the necessary computations.

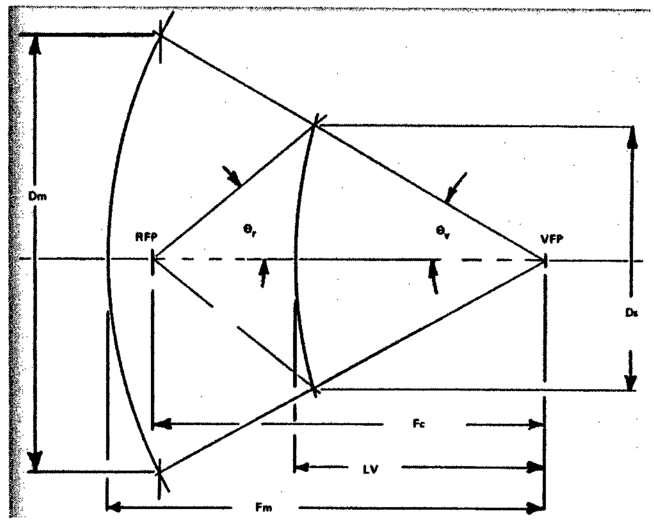


Figure 1

Materials Evaluated

A materials evaluation was conducted to enable selection of a material that would simultaneously fulfill the requirements specified for the manufacture of non-planar printed circuits.

Initially, a chart was prepared listing the significant properties of various candidate materials. A list of abbreviations for these materials is shown in Table 1. Considered were those properties and/or characteristics which were assessed to be of greater importance to the success of the project. Foremost among the material attributes were (1) platability; (2) formability, (3) thermal stability; (4) structural adequacy; (5) process repeatability; and (6) cost.

The more current polymers were listed as well as some standard plastics and composites. Included for comparison were properties for aluminum, brass, and steel.

Any material that was acceptable for use on the project had to be platable by semi-additive processing. Therefore, any

TABLE 1. LIST OF ABBREVIATIONS

Abbreviation	Chemical Name
PPS	Polyphenylene sulfide
PEI	Polyether-imide
PAI	Polyamide-imide
PPO	Polyphenylene oxide
ABS	Acrylonitrile butadiene styrene
PBT	Polybutylene terephthalate
PVC	Polyvinyl chloride
Mindel	Polysulfone/ABS alloy

material that failed to meet the platability aspect was unacceptable for use in non-planar hardware.

In view of the foregoing evaluation, a decision was reached to apply the material Mindel A-650 to this application. Mindel is an alloy of ABS and Polysulfone. As such, it provides the superior plating attributes of ABS, with the higher thermal stability and strength properties of the Polysulfone.

It is also worth noting that the material PPO could also be fabricated and processed successfully with the same tooling. The same statement applies to the PEI (Ultem) material.

Detail Design Configuration

Incorporated into the body of the main reflector of the nonplanar antenna are the provisions for the four port square waveguide feed and the cavities in which the connectors, baluns, and feed wires connect to the broad band spirals. Provision is also included for the mounting of the features of the subreflector support structure and the subreflector. Figure 2 shows the main parabolic reflector detail.

Tooling was designed and fabricated to permit the injection molding of the main reflector and the subreflector. The gating features in the molds were tailored during the molding process so as to minimize sinks and provide for correct filling of the mold, replicating the desired surface finish on the molded part.

Tooling for the main reflector includes design features required for (1) proper heating of the mold, (2) gate sizing to insure complete fill of the mold during injection of the plastic, (3) good surface finish, and (4) freedom from undesired sinks in the reflector surface and spiral cavity feature.

Tooling for the subreflector likewise was designed to achieve proper fill, exhibit good surface finish, and prevent sinks in the reflector surface.

Spheroidal Measurement Difficult

Inspection of the non-planar antenna components proved more difficult than originally anticipated. A closer examination of the problem revealed that accurate results could not readily be obtained using conventional measuring techniques. The difficulty in obtaining accurate measurements occurred primarily on the topological curved surfaces even by using a validator, a device capable of measuring any object up to 4 feet x 4 feet x 3 feet to within 0.0005 inch.

The reason for this difficulty centered on the geometry of the measuring probe, which was used to establish the position of the topological curved surfaces relative to a fixed coordinate system.

A solution to the problem was to compensate for the geometry of the probe by actually determining the point of contact the probe made with the curved surface.

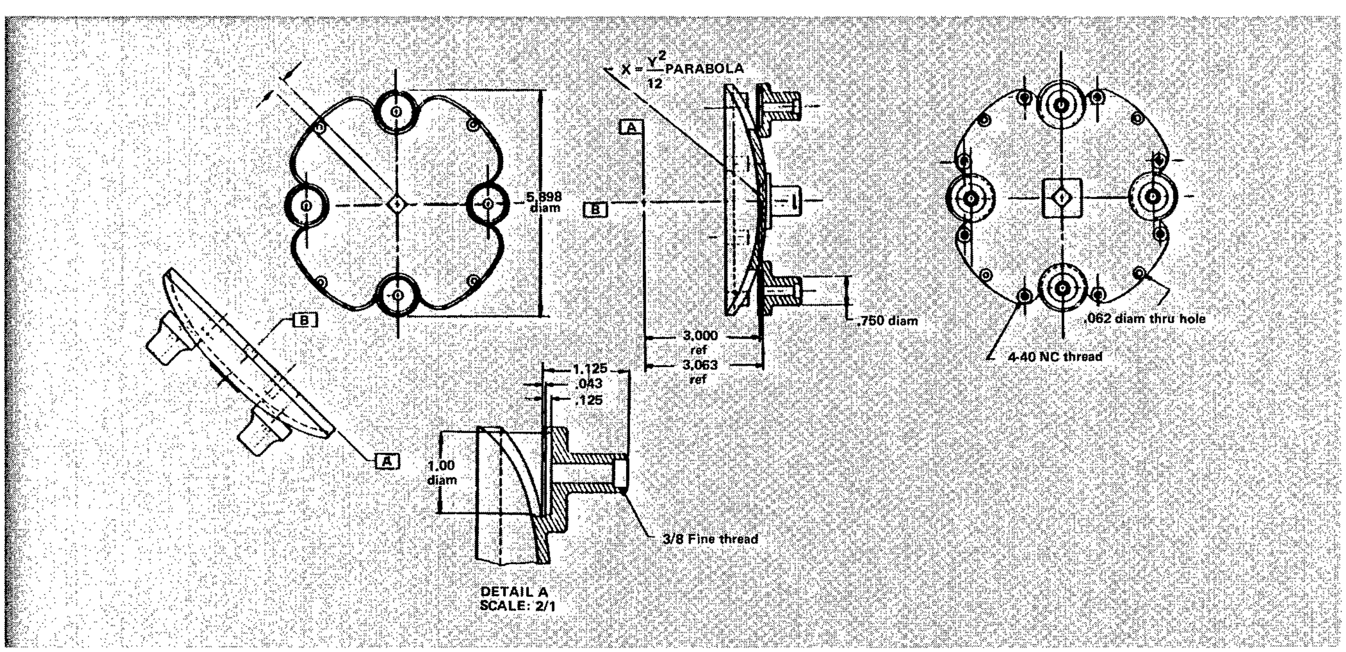


Figure 2

In this particular case, a probe with a spherical tip was used. The spherical tip was used to prevent damage of the parts or tools. However, the spherical tip probe affected the accuracy of the measurements made on the curve surface by the validator. This decrease in accuracy was due to the fact that all the measurements are referenced from the tip of the probe where contact with the measuring surface is assumed to occur.

This, however, is not what happens when measuring these curved surfaces. Contact may occur on the sides of the probe's spherical tip, depending where the probe is on the curved surface. In order to compensate for this problem a computer program was written that proved to be very laborious and time consuming. So an alternative method was found to measure the antenna parts and tools.

Solution Reached

This method involved the use of a computer-controlled three-dimensional measuring machine manufactured by Zeiss. The theoretical procedures used by the Zeiss machine check the topology of spatially curved surfaces using computer controlled 3-D measuring machines. Included among such surfaces are geometrically complex gears, thread profiles, impeller pump and turbine blades and wind tunnel or towing tank models. Modern computer numerically controlled coordinate measuring machines are now capable of making such measurements through rapid point-to-point scanning and computer analysis.

A mathematical representation of the nominal surface is generated and stored in a main frame computer and compared with the actual surface as measured by the coordinate measuring machine. Deviations between the two are illustrated graphically on an x-y recorder by superimposing the network of actual points on the nominal point network. Comparison of the actual surfaces before and after various types of processing permits analysis of the topological effects of such processing.

General Considerations

When checking the forms of spatially curved surfaces, the following requirements must be addressed:

- The nominal surface must be expressable as a mathematical model.
- The actual surface must be measureable with the required accuracy in a reasonable period of time.
- Quantitative comparison of the actual and nominal surfaces shall be possible.
- The causes of any deviations shall be interpretable to permit optimization of the manufacturing method.

While the measurement of geometrically simple bodies such as cylinders and cones is relatively easy, it becomes significantly more difficult in the case of three dimensional curved surfaces.

A flow chart covering the design, manufacture, and checking of compound curved surfaces is shown in Figure 3. Main frame computers permit simulation of complete manufacturing processes based on machine kinematics and tool geometry. These methods result in mathematically defined surfaces which can be compared with machined surfaces through the use of sophisticated, high speed coordinate measuring machines.

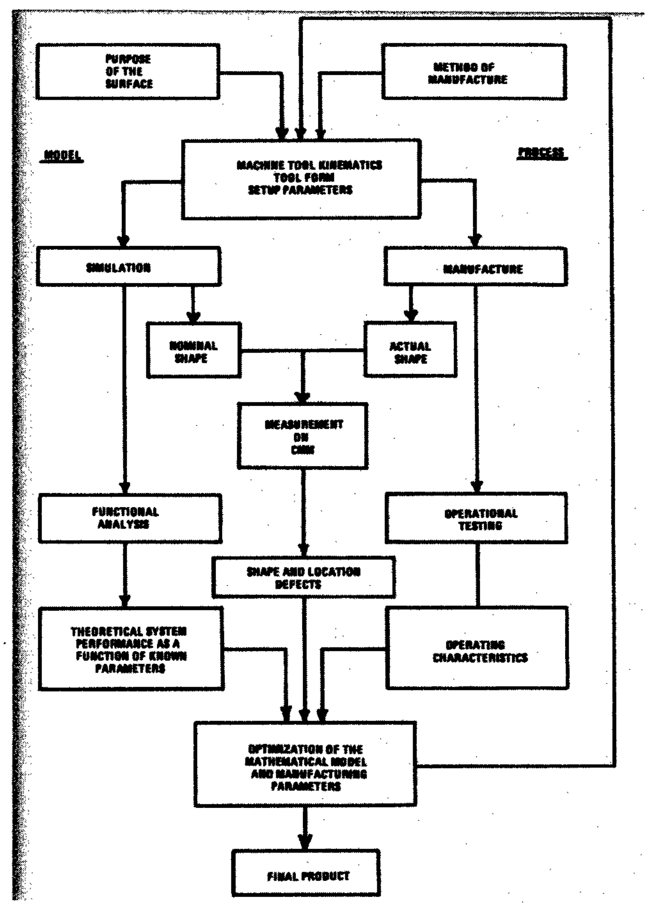


Figure 3

The Actual Measurement

When measuring compound curved surfaces the "continuous probing" mode of the Zeiss system is particularly beneficial—the machine can follow the contour of a part in a predetermin-

ed direction in the same manner as the follower head on a 3-D copy mill. The automatic positioning control which is actuated at probe contact scans the free axis of the machine until the inductive measuring system in the probe head is brought to its null point. The moment this condition is achieved all three machine coordinates are automatically transmitted to the computer. Thus, for instance, the probe may be locked in the X axis and be made to traverse to predetermined locations in the Y axis, while automatically following contour changes of the part in the Z axis; the machine will remain at a preselected X-Y location until the probe has been nulled in the Z direction and the position information transmitted to the computer. It will then proceed to the next X-Y location.

Quantitative relationships between setup variations and resulting form variations cannot be established without computer data processing. Analysis of measurement results must also be done by computer. The nominal surface is calculated by simulation of the manufacturing process. The input parameters for the calculation correspond to the setup parameters. This relationship is taken advantage of in analysis of the surface deviations. By introducing slightly changed machine setup parameters, the computer can generate variations of the original nominal flank, changing the form and location of the point network. An additional software routine in the main frame computer compares the desired nominal flank with the numerically altered flank and develops a list of deviations. The simulated errors then are compared with the measurement results and after several iterative steps the theoretical setup parameters responsible for generating the actual gear can be pinpointed and evaluated.

The absolute variation in the part tolerance is presented on the Zeiss readout sheet as Form Error. The Form Error is the absolute deviation about the theoretical curved surface. This means that for a form error of 0.00167 inch, the actual curve surface varies .0008 inch about the theoretical curve.

The Zeiss data indicated that the form errors of the paraboloid and hyperboloid curved surfaces were .0011 and .0008 respectively, within the specified tolerance, 0.0013 inch.

Spiral Antenna Design

The design of the spiral antennas required for this effort was undertaken initially using an equiangular logarithmic spiral approach. Using the one-inch diameter specified and establishing that a two arm spiral would be used in the application, the feed point dimensions were set at .050 inch. With these features defined, the equation of the equiangular spiral was written. This equation was used in the computer program to generate the coordinates of the spiral geometry. The coordinates thus obtained were then used to enable the generation of art masters via computer aided design using a photo plotter.

The artwork was applied to additively plated polysulfone substrates and the spiral pattern etched in the metallization to produce a functional circuit board. Additional details required for the assembly of a functional antenna were fabricated, permitting the functional evaluation of the broad band spiral antenna.

Subreflector Grid Artwork Generation

The artwork pattern formation for printing the hyperbolic subreflectors was initiated in the computer aided design group and recorded on magnetic tape. The information stored on the tape was the precise dimensions of the grid and grid spacing (0.0314 inch square by 0.003 inch space). This magnetic tape was sent to the Electromask Microphotography Facility for final processing on the Series 2500 Pattern Generator/Image Repeater. This device uses laser light for exposing a light sensitive polymer. The polymer is developed in a chlorinated hydrocarbon solvent and then etched in sulfuric acid yielding the desired pattern. The residual polymer is stripped in acetone and inspected for dimensional accuracy.

Cost Comparison of Alternate Methods

Several manufacturing processes were studied before injection molding was selected. Low cost dictated the method used in the development of these parts. Labor intensity is an excellent criteria for cost if the raw materials are not expensive and have similar values.

The manufacturing processes studied were:

- Injection Molding
- Precision Casting
- Machining
- Electro-Forming.

Each of these processes are evaluated as though they are being made in production. The tooling cost for injection molding, precision casting and electro-forming would be similar. The tooling cost for NC machining would be less, but only by about one half.

Task 2 Requirements

The cylindrical printed wiring board was to be nominally five inches in inside diameter and 6 inches long. The eight-layer cylindrical circuit board was to have a 1/2-inch square grid pattern of 10 mil wide copper circuits. All layers of the multilayer grid had pads at the intersection of the grid lines.

Drilled holes were plated through, well centered on all pads of each layer, and no larger than 0.042 inch diameter.

Materials and Process Evaluation

The basic intent of this program was to find a material/process system to produce military printed wiring boards having a cylindrical shape. This system was to have the highest poten-

tial of producing additive plated printed wiring boards to military test requirements. Although polyimide-acrylic material was recognized early as a prime candidate, other types of materials were evaluated during this phase to provide comparative data for the polyimide-acrylic materials.

Five potential constructions were evaluated to manufacture cylindrically curved single-sided, double-sided, and multilayer printed wiring boards. Extensive work was done to evaluate each processing step in the various constructions for complexity, cost, ease of manufacture, and potential for having a 95 percent confidence level.

(1) **Glass-reinforced polyimide supported copper-clad substrates** capable of being bonded with B-stage glass supported polyimide adhesive layers was the first construction to be evaluated. Here, the innermost pre-etched layer would be wrapped around a mandrel and bonded with a B-staged polyimide adhesive system. Subsequent pre-etched layers .007 inch thick would be registered with the first layer by the use of tooling pins and then bonded with adhesive layers. A unique bonding method was developed by General Dynamics Pomona several years ago to laminate composite wings and fins. This methodology is called elastomeric pressure bonding. A silicone potting resin is cast to a cylindrical shape and placed against the layers to be bonded. The layers and silicone form are restrained by the inner mandrel and outer box. The assembly is then placed in an oven at 350 F for 1 hour, causing the silicone rubber to expand and exert uniform pressure of 50 psi, thus allowing the B-staged polyimide adhesive to cure. Using this method for bonding eliminates the need for elaborate tooling and expensive presses.

(2) A similar approach was taken using **unreinforced polyimide supported copper-clad substrate** (Kapton by Dupont). These flexible layers were bonded using B-staged glass supported polyimide adhesive layers. By effectively removing half of the glass reinforcement, it was felt that conventional processing steps could be utilized. After processing, the laminate was wrapped around the mandrel. During this process the board delaminated and cracked due to the stiffness of the glass reinforcement. This approach was abandoned.

(3) An evaluation was made of **polysulfone copper-clad laminate samples.** The samples were pre-etched and thermoformed using heat and pressure over a mandrel. This system looked promising until we found that Norplex (sole source of polysulfone/Cu clad laminates) had decided that the market could not support their product and a production facility was never built.

(4) A fourth construction evaluated was the use of **injection molded polysulfone.** By utilizing injection molding techniques it is possible to eliminate the costly drilling step. Pins can be built into the mold to allow for "molded in holes". Expensive tooling would be required to injection mold the four individual components. Each layer would have to be additively plated, imaged, and etched in a cylindrical configuration. This processing sequence, very similar to that previously described in (1), is very complex, costly, and unreliable.

(5) The evaluation led us to the use of **all flexible materials** manufactured by Dupont. Flexible printed wiring for electrical interconnections has been an important production product for years. They have replaced mazes of "hard wiring" for assembly simplification, neatness, maintainability, and reliability, all of which are crucial in military electronics. Electronic circuit boards made by flexible polyimide are lower weight and require less space than the wiring systems which they have replaced. Flexible polyimides are more reliable, due to the fixed and reproducible spatial relationships between electrical circuits within the assembly, based on actual experience with weapon system reliability data.

TASK 2: CYLINDRICAL CIRCUIT BOARD

Process Optimization

General Dynamics performed the development and testing required to optimize the manufacture of the primary and secondary mirrors of the parabolic 94-GHz antenna, emphasizing rigidity, low thermal expansion, and thermal integrity. They also performed the development and testing required to optimize the manufacture of cylindrical multilayer printer wiring boards, and manufactured a sufficient number of boards to establish the reliability of the process to a 95 percent confidence level. A lot size of 20 pieces was sufficient to demonstrate an 85 percent reliability at a 95 percent confidence level, assuming no failures in the lot.

General Dynamics proposed an implementation plan which detailed the steps to be taken by the contractor to implement the results of the Basic and Option I efforts.

The manufacture and functional testing of five 94-GHz dish antennas included only those items required for test in the applicable referenced military specifications. No RF testing was attempted.

Support and Process Documentation

General Dynamics prepared a design package and support documentation that detailed step-by-step processing and process and solution control, to the extent that the developed process and results could be duplicated by others from the furnished package. They also assembled a pilot production line embodying the final developed processes and used it to qualify the process. To minimize expenses involved in establishing a pilot production line, off-line and/or unbalanced facilities were utilized.

A run of 16 94-GHz dish antennas and a run of 20 8-layer cylindrical boards with plated-through holes were completed for process and line verification.

Production Costs Drop 24 Percent

Compliant Air Bearing Gyros Built Better, Cheaper

Under U.S. Army Missile Command sponsorship, Honeywell, Inc. (St. Petersburg) made significant advances in magnet fabrication, mirror fabrication, compliant layer molding, rotor balancing, and gyro testing—all to demonstrate improved manufacturing processes for the Compliant Air Bearing (CAB) Gyro. The process and tooling developments listed below have resulted in a 24 percent reduction in the projected production cost of the CAB.

- Injection molded magnet
- Magnet patterning process
- Diamond turned mirror fabrication
- Investment cast torquer housing
- Multicavity compliant layer molding
- Rotor balancing process
- Gyro test process.

Not only are the cost reductions significant, but the credibility of the estimates and the technical credibility of the CAB as a seeker gyro for cannon launched projectiles has also been established.

Reconfigured Design Necessary

Contract objectives were to develop improved manufacturing methods and technology for the production of a hydrostatic Compliant Air Bearing (CAB) gyro and to demonstrate the significant cost advantage this technology represents over conventional seeker gyro technology. The contracted work was based upon the CAB gyro assembly developed previously by Honeywell in conjunction with MICOM. Program effort was directed to implement the standard Copperhead folded optics system, and the CAB gyro was reconfigured to accommodate new optics and laser detection hardware. All subsequent manufacturing methods development was based upon this new gyro configuration.

The contract performance was divided into two phases—the Basic Program and the Option I Program. In the basic program, the methodology was developed for the manufacturing and assembly processes for each element of the CAB gyro. The Option I program demonstrated the fabrication, assembly, and test processes during the build of a pilot production sample of CAB gyros.

WILLIAM G. ROBERTSON presently is assigned to the Parts Acquisition Program Office at MICOM. He received a BME from Marquette University and worked for Lear, Inc. for three years before going to work for the Army Ordnance Corps at Redstone Arsenal in 1952. In 1960, he returned to private industry for 14 years; in 1974, he returned to MICOM, assigned to Inertial Systems Development in the Guidance and Control Directorate. He has approximately 27 years of design experience in gyros and stabilized platforms.

NOTE: This manufacturing technology project that was conducted by Honeywell, Inc.'s Avionics Division was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Bill Robertson, (205) 876-1020.

Performance Objectives

The CAB gyro seeker including the gas supply system is shown in Figure 1, while the major elements of the device are shown in block diagram form in Figure 2. The gyro includes a planar mirror on the front of the rotor, and this mirror is located in the exact same axial position in the projectile as the Copperhead mirror and in the same position relative to the pivot axis of the rotor. Therefore, the gyro is directly interchangeable with the Copperhead optics and detector assemblies. The unit is designed to exactly fit the Copperhead 155-mm projectile envelope and interface directly with the guidance electronics housing at the aft end of the gyro support housing.

The CAB gyro is designed for an angular momentum that provides drift performance within the Copperhead requirement. The spin axis to cross axis inertia ratio has been controlled by design, thus ensuring stable, nutation free operation. The gimbal angle freedom exceeds Copperhead requirements. Performance after launch shock of 10,000 g has been verified by test.

The salient features of the design are as follows:

- Two-Axis "Free Rotor" Air Bearing Gyro
- Compliant Bearing (EPDM)
- DC Torquing
- Optical Gimbal Angle Pickoffs
- Integral Gas Supply System
- Planar Mirror—same size as Copperhead
- Standard Copperhead Optics/Detector.

The advantage of this design over conventional seeker gyros can be summarized as follows:

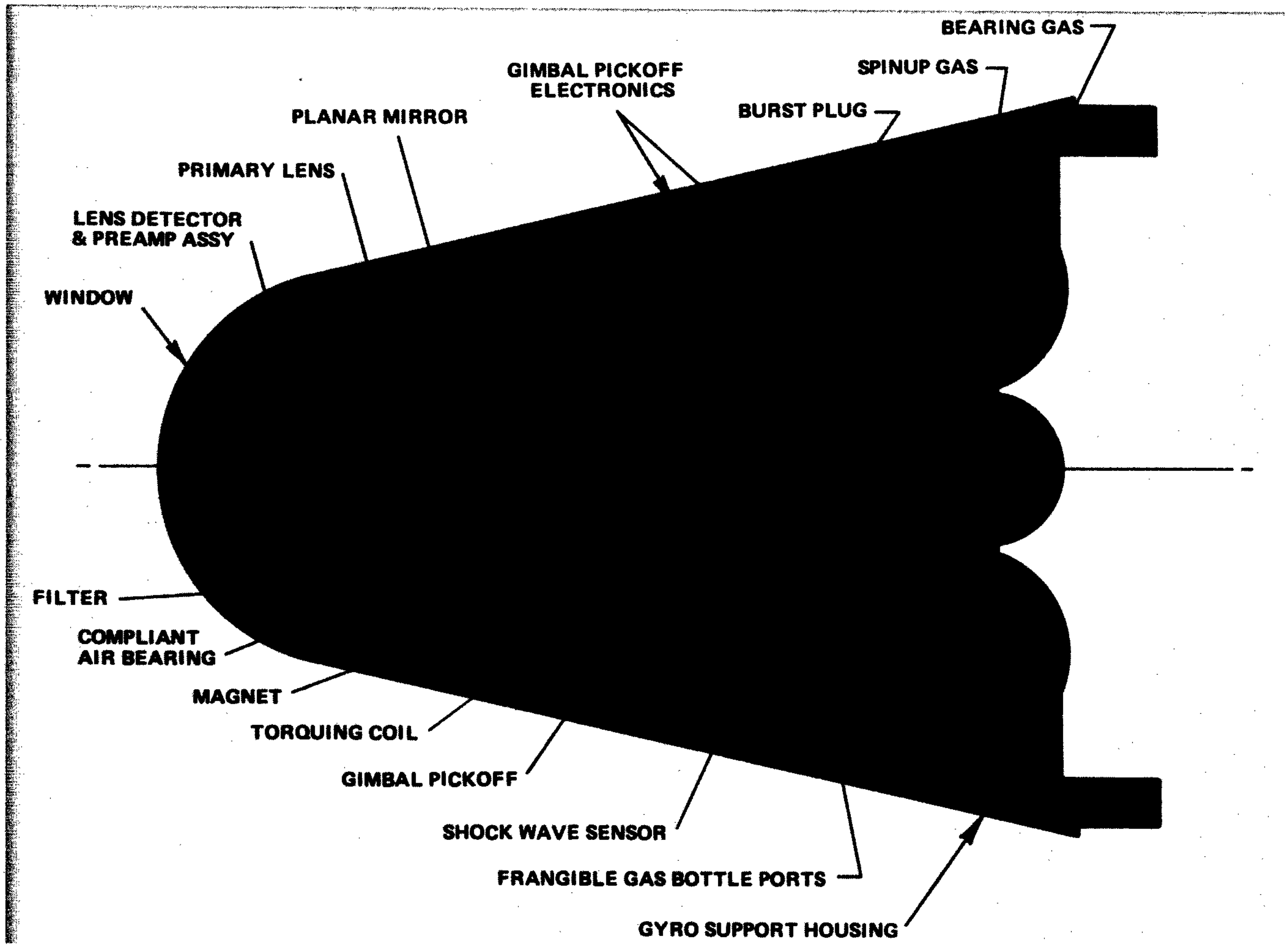


Figure 1

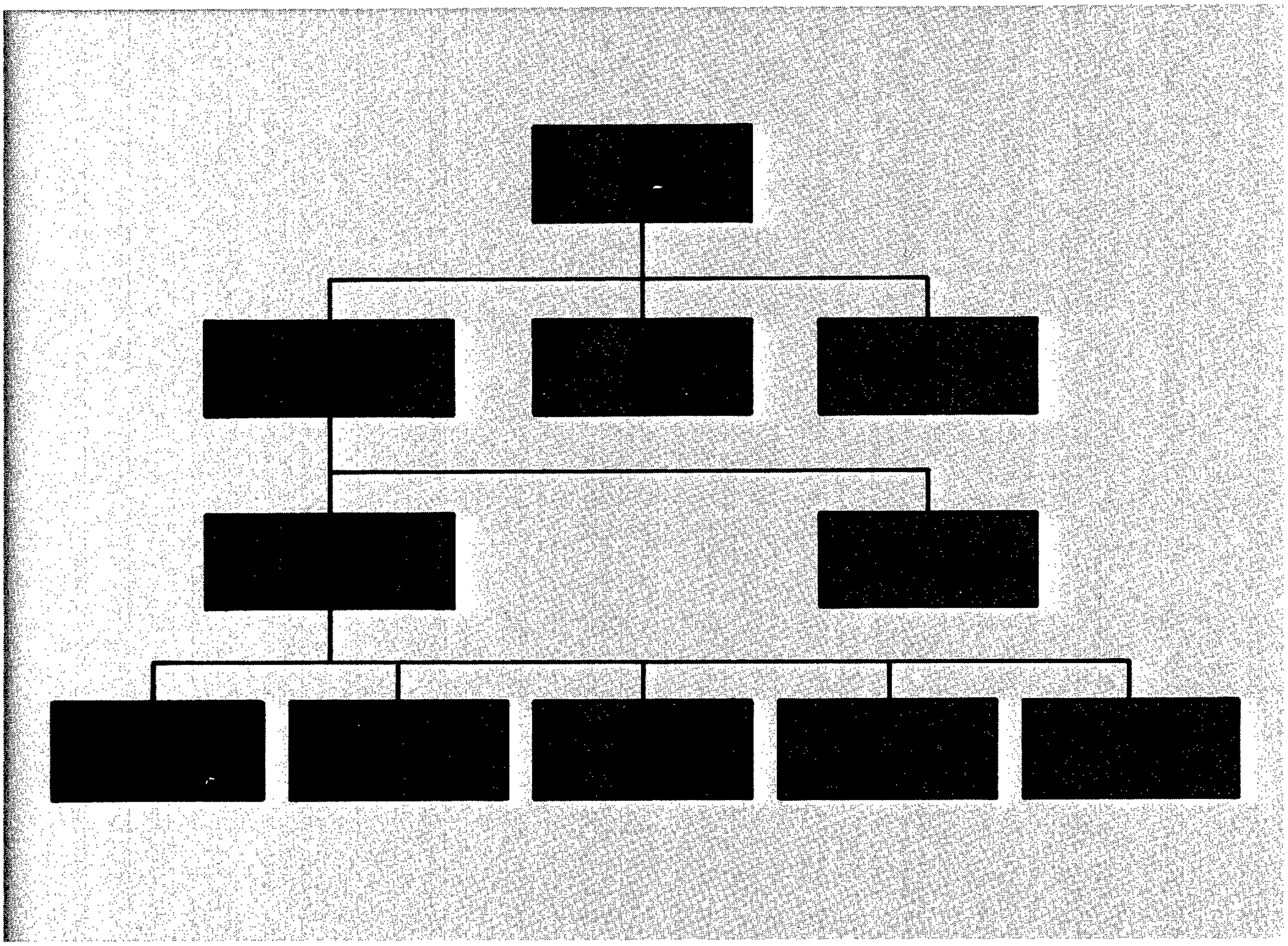


Figure 2

Cost

- Minimum Parts Count
- No "Gotcha"
- No strategic materials (no titanium or cobalt)
- Molded elastomeric bearing cavities

Performance

- Constant wheel speed (hero engine)
- No Coulomb friction (air bearing)
- Low Noise (optical pickoff)

Electronics

- Continuous DC Torquing (synchronization with speed not required)

Operation

A squib is initiated after launch, fracturing the seal on the bearing gas bottle allowing gas to flow through a gas flow regulator to the stator stem and exiting out 16 orifices around the spherical diameter of the stator, thus "levitating" the rotor. Immediately, the gyro torquer is activated, positioning the rotor for spinup, then the gas is released from the spin bottle by fracturing its seal. The spin gas flows through channels in the support and torquer housings exiting from tangential nozzles in the torquer housing. The exiting gas impinges on the turbine ring on the rotor assembly and accelerates the rotor to operating speed. The rotor speed is sustained throughout the mission by venting the center of the bearing with tangential "hero nozzles" in the rotor assembly. On the forward rotor half is mounted the planar mirror which reflects the incoming laser energy onto the forward mounted detector assembly.

Also mounted on the rotor is a magnet which provides the magnetic flux for torquing the rotor through a dc torquing system in both pitch and yaw. The spherical outside surface of the magnet is coated with a sawtooth reflective pattern from which the optical gimbal angle pickoffs read pitch and yaw angular displacements. Mounted on the torquer housing assembly surrounding the rotor and stator assembly are the pickoff assemblies which consist of an LED and a phototransistor. The output of the pickoffs is a pulse width modulated output with the percent modulation proportional to gimbal angle. Gimbal pickoff electronics are included in the gyro assembly to convert the output to a linear dc output proportional to angle with appropriate filtering. Also mounted to the torquer housing are the torquing coils for the dc torquing system. Mounted on the forward surface of the torquer housing is a lens housing which supports the standard Copperhead optics and detector assembly hardware.

The CAB Gyro Seeker uses the standard Copperhead window and interfaces mechanically with the Copperhead electronics housing. Only minor changes are required in the Copperhead electronics to integrate the CAB. A new torquer drive electronics board and modifications to the sequencer board associated with Gyro initiation timing sequences will make the CAB gyro seeker completely compatible with the Copperhead projectile.

MANUFACTURING PROCESSES

The objective of this phase of the program was to develop improved lower cost manufacturing processes for critical elements of the new folded optics gyro design.

Rotor and Stator Assembly

The rotor and stator assembly is the heart of the CAB gyro seeker and special emphasis was placed on critical elements of this assembly. Rotor and stator assembly is shown in cross section in Figure 3. The critical elements of this assembly which offered the greatest potential payback are the Torquer Magnet, the Planar Mirror and the stator assembly. Significant improvements were developed in each of these elements. The remaining parts, while important to the gyro function, are conventional machined parts made of low cost materials and therefore are not treated in any detail.

The torquer magnet on the original baseline direct optics CAB was a complex and expensive assembly. The magnet was made of (3) INDOX ceramic rings. Each ring was independently machined, ground to size and independently magnetized prior to bonding them together. An epoxy coating was bonded onto the spherical surface and then machined to provide a nonporous uniform surface for plating the optical pattern. The plating was a three step electroplating process using copper, nickel and a gold flash. After plating the whole magnet, the pattern was formed by selectively removing the plating using a mechanical mask and abrasive blasting. The ceramic material was selected to avoid the use of expensive and strategic materials such as the cobalt containing Alnico series; however, the use of ceramic dictated extensive grinding of each magnet segment. The use of three segments independently magnetized was required in order to achieve the desired flux distribution over the spherical diameter. The required uniformity could not be achieved with a one piece magnet with the available magnetizing equipment.

The key to success involved magnetic orientation of the particles in the mold so as to achieve maximum flux density per unit volume of molded material. The design of the tooling resulted in achieving all desired final dimensions as molded and provided a void free uniform spherical diameter on which an optical pattern can be directly applied.

The magnetizing of the one piece magnet is critical to achieving a uniform torquer scale factor independent of the gimbal angles. This scale factor is a function of the uniformity of the flux density after magnetization. Magnetizing was done using the unique two coil radial magnetizing fixture shown in Figure 4. The nesting of the magnet and the sizing and positioning of the coils were carefully designed to achieve the optimum uniformity. A prototype gyro built with the new one piece magnet and magnetized in this fixture was evaluated for scale factor versus angle.

After magnetization a reflective optical pickoff pattern is generated on the spherical O.D. of the magnet as shown in Figure 5. The high cost of the original concept was caused by the need

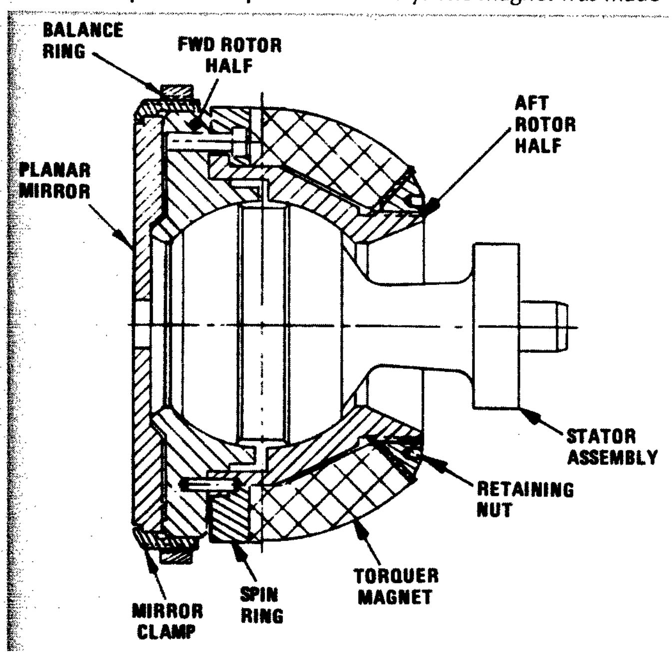


Figure 3

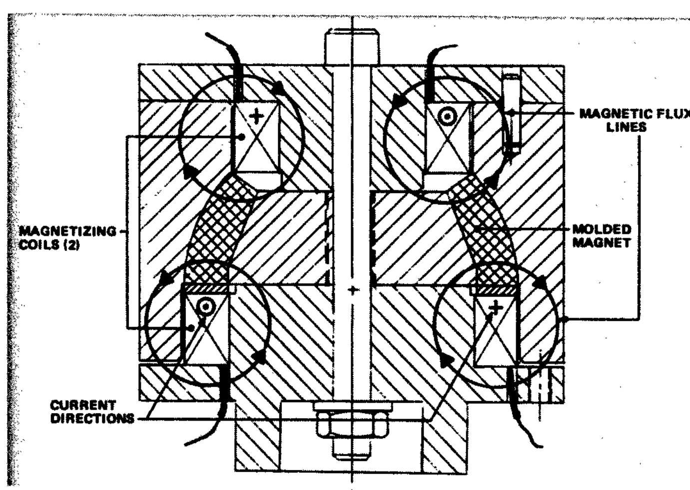


Figure 4

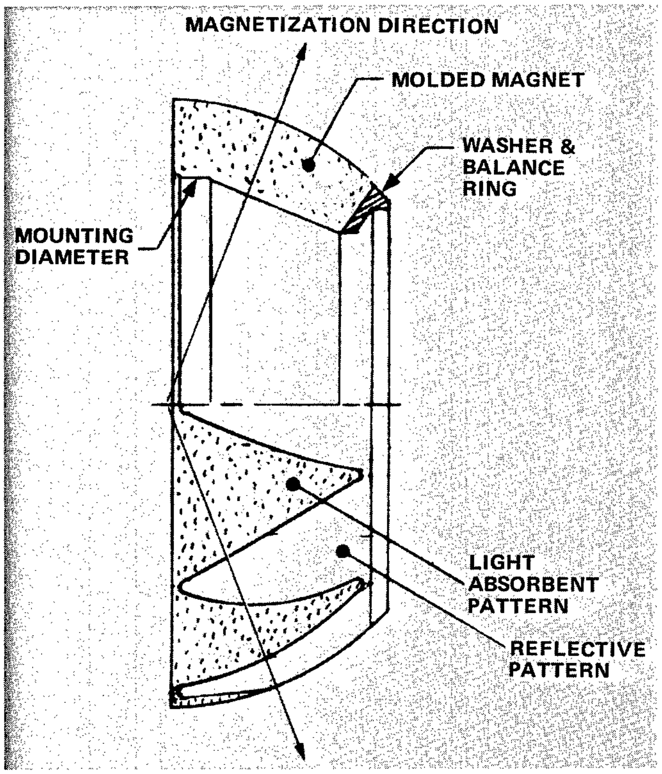


Figure 5

to seal the pores in the ceramic mateial with epoxy and the costs of the multiple plating operations. The molding process developed by Tengam produced the desired surface directly from the mold. Special testing of the pickoff assemblies was conducted to establish that the desired pickoff outputs could be achieved with other than a gold reflective surface. It was determined that adequate performance could be achieved with an optical quality white paint. This permitted the use of a low cost paint spray operation to replace the multiple electroplating operations. Standard adhesive tests were used to verify the integrity of the paint after cure. As in the original process, the pattern is formed by abrasive blast removal of absorbent areas using a simple mechanical mask. The geometrical accuracy of the pattern is controlled by the masking fixture.

The cost saving resulting from this new magnet manufacturing technology is substantial. The unit cost comparison is based upon estimated cost for the production of 130,000 magnet assemblies at 4,000/month. The total savings per unit represents a 97 percent reduction.

The CAB Gyro design objectives were to design a mirror equivalent in capability with that currently used on Copperhead, and to develop a mirror fabrication process which would be less expensive than the current Copperhead process. The Copperhead design utilizes an aluminum substrate which is integral with the gyro rotor frame. The cast surface is machined and nickel plated using an electrolytic plating process. The nickel is then ground and lapped to achieve the required surface finish and flatness. The planar mirror reflective surface is formed by vapor depositing a very thin layer of nichrome and very pure gold onto the lapped nickel surface. The Honeywell objective was to eliminate the labor intensive lapping operation and costly electrolytic plating process. This was accomplished by diamond single point turning of the aluminum substrate. In this concept the surface finish and flatness of the substrate is attained directly on the aluminum without the need for a heavy nickel plating and subsequent lapping.

The surface finish, flatness and mirror quality were successfully accomplished using the diamond turning process. This enabled Honeywell to complete the mirror process with a vacuum deposition of the highly reflective gold surface.

The vacuum deposition was accomplished at Honeywell's St. Petersburg manufacturing facility.

The reflectivity of the coated mirrors produced to demonstrate the process all met the reflectivity requirement. The mirrors were tested at the Bryson Laboratory in Safety Harbor, Florida. Tests were made at three different wavelengths.

The final mechanical configuration of the mirror provides the clear aperture required by Copperhead. The mirror is clamped to the forward rotor half with a threaded ring around its mirror surface through cannon launch. Five mirrors have been successfully cannon launched with two of the five tested afterwards at the MICOM simulation center. Honeywell's engineering estimate is that a 30 percent savings will be realized.

For the stator assembly, the folded optics configuration required locating the reflective surface of the mirror forward of the gimbal axes. Also, the rotor gimbal freedom had to be increased to meet Copperhead limits. These two requirements dictated a reduction in the bearing diameter. Other changes which resulted from converting from direct optics to folded optics were as follows:

- Shaft machining simplified
  Detector cavity deleted
  Leadwire holes deleted
- Orifice size increased
- Two orientation pins deleted.

The design of the stator assembly involves the machining of two pieces which are subsequently epoxied together to form all

the gas passageways. Both parts are machined from 7075 aluminum for the strength necessary to survive the cannon launch. Several successful cannon launches have verified the structural integrity of this assembly. Sixteen bearing orifices are drilled in the stator. The length to diameter ratio was minimized to control tool breakage. The spherical diameter of the ring is ground to a tolerance which controls the air gap when mated to the molded rotor halves. The projected unit cost savings represents a 28 percent reduction.

Torquer Housing Assembly

The torquer assembly originally consisted of a torquer housing, a spinup nozzle assembly, (4) torquing coils and erection coil. Several new design and manufacturing techniques were developed on this program resulting in significant cost reductions.

The improvements incorporated included:

- Converted housing from a machined part to a casting.
- Made spinup nozzle assembly integral with the torquer housing.
- Deleted the erection coil assembly by revising the spinup sequence.
- Developed production coil winding and forming tools.

A torquer housing casting was developed on this program. The investment casting tooling was designed and fabricated by Armstrong Mold Corp. in Syracuse, New York, and 30 castings were produced verifying the producibility concept. The housing provides the following functions.

- Base mounting diameter for interface with gyro.
- Built in positioning and support for torquer coils.
- Orthogonal planes for gimbal pickoff mounting.
- Mounting structure for Copperhead detector hardware.
- Integral spinup nozzles and passageways.

The casting is made from aluminum alloy A356-T6 per QQ-A-601. The castings receive radiographic and penetrant inspection per MIL-C-6021 Class 3 Grade C. The structural integrity of the cast housing was verified by successful cannon launches.

Machining of the casting is needed to

- Provide windows for mounting the two gimbal pickoffs.
- Size mounting diameters and faces for gyro base and optics assembly.
- Provide gas vent holes.
- Provide spin gas holes and nozzles.
- Provide tapped holes for attaching the base, lens support housing and optical pickoffs.

The torquer coil winding and installation process is basically unchanged from the original concept. Each of the (4) coils is identical and conforms to the envelope. Winding and forming fixtures were designed and developed to control the final sized form after impregnation and curing.

The torquer coil assemblies are cemented into the torquer housing, and the coils are self-aligned and positioned by the as-cast bosses in the center conical surface of the housing. The bosses also support the coils during cannon launch without the need for an expensive potting operation. The erection coil was also eliminated in the new concept by a simple change in the torquer rebalance sequencing electronics. Thus, just after bearing levitation the electronics provide for torquing the rotor first to a fixed position against the stop and then a controlled current is applied to each winding to torque the rotor to an on-axis condition just prior to spinup. The cost savings resulting from the new torquer housing assembly represents a 15 percent reduction.

The pickoff assemblies and the pickoff electronics are composed of two pickoff assemblies, one to sense pitch axis angular displacements and the other to sense yaw axis angular displacements. The pickoffs consist of an LED which illuminates the triangular reflective pattern on the outside diameter of the rotor magnet and a phototransistor which receives the reflected energy. The photodiode produces a voltage pulse for each of ten triangular patterns during one revolution of the rotor. The pickoff is positioned such that at gimbal null the pulse width represents a 50 percent duty cycle.

Gimbal deflections from null therefore either increase or decrease this modulation in direct proportion to the angle of displacement. The pickoff electronics convert this pulse width modulated output into a dc voltage directly proportional to angle for each axis. The pickoff electronics also produce a continuous ouptut indicating rotor speed. The rotor speed information is used for test purposes and could also be used to compensate torquer scale factor in the system electronics.

A task in this MM&T program was to develop the manufacturing methods for the pickoffs and pickoff electronics based upon the new folded optics gyro configuration.

The pickoff assemblies were not substantially changed as a result of the redesign to the folded optics gyro design, except that the positioning of the pickoff had to be revised as shown in Figure 6. The manufacture of the assembly consists of a molded plastic holder for mounting the optical components. The TIL23 Light Emiting Diode and the TIL601 phototransistor are both made by Texas Instruments. The mold for casting the pickoff holder was designed and built by Honeywell. The parts are mold-

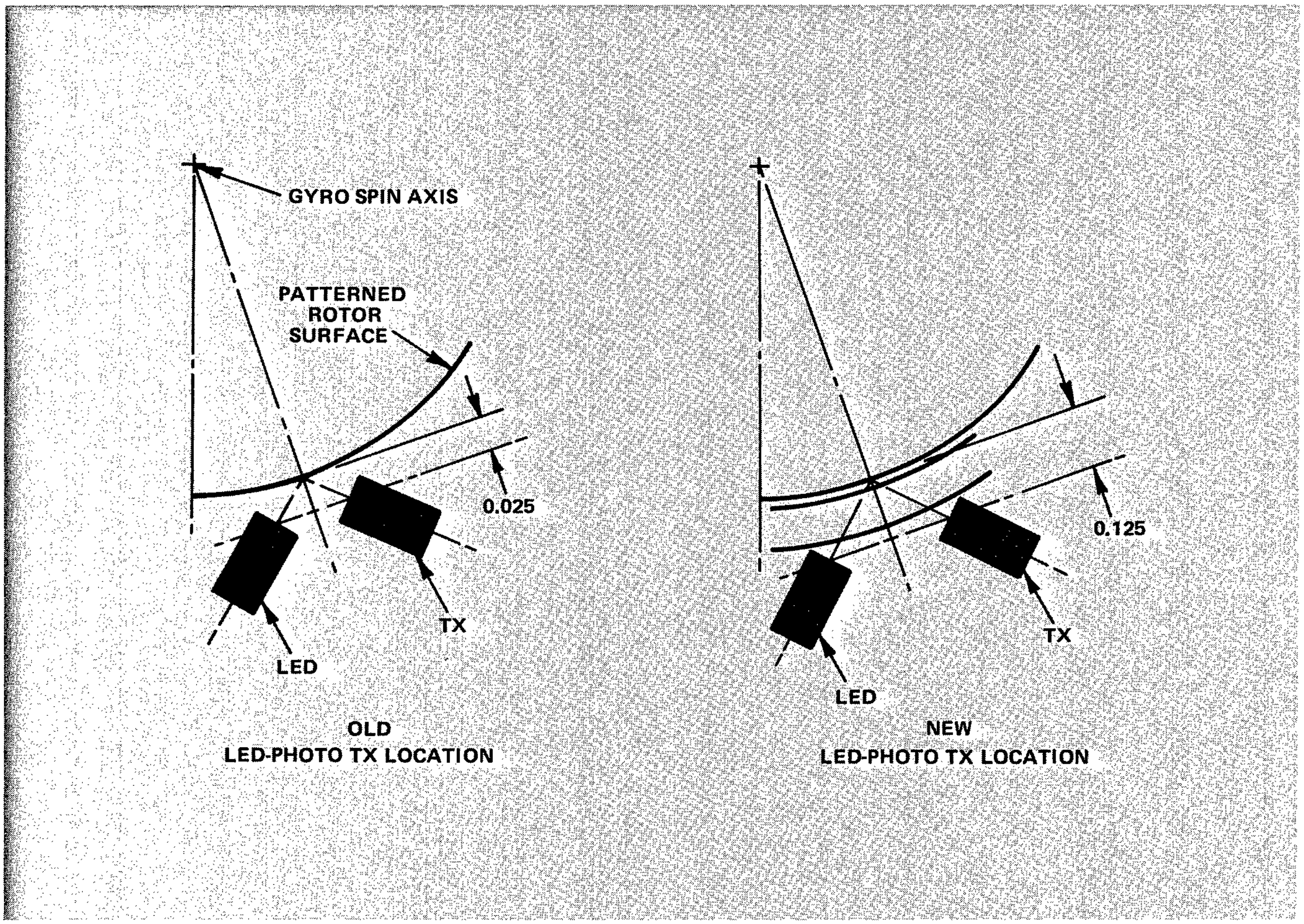


Figure 6

ed using a highly filled epoxy for dimensional stability and thermal conductivity. Minor secondary machining is required to drill the holes for the component mounting and to true the mounting surface.

The pickoff electronics accept the signals generated by the LED/phototransistor assembly. The rotating pattern on the rotor produces a pulse duration modulated (PDM) signal. The electronics are identical in both channels, except in one channel an output is added for purposes of monitoring wheel speed. The pickoff electronics develop a dc voltage level that is linearly proportional to rotor position. The electronics also contain biasing networks that allow the electrical null to be adjusted to coincide with the mechanical null.

The manufacturing process for the pickoff electronics was modified as a result of the conversion from direct to folded optics. The original concept utilized two printed circuit boards with discretes, mounted on the sides of the torquer housing. In the new folded optics design the area available for electronics was significantly reduced because the gyro had to be set farther aft to make room for the front end optics and detector. This necessitated the use of a vertical "donut" shaped sandwich assembly consisting of a lower board assembly and an upper board assembly. In addition the lower board had to be segmented so as to not interfere with the three shock wave sensors mounted on the gyro base. Because of the many interconnects required it was decided to utilize flex tape interconnect between boards and between the upper board and the pickoff assemblies.

Honeywell selected the Parlex Corporation in Methuen, Massachusetts to develop the printed wiring boards. Each printed wiring board consists of a single layer Kapton flexible cable sandwiched between two double sided rigid printed wiring boards. Approximately 15 of each assembly were produced by Parlex with excellent results. Component mounting and final assembly including select resistors and conformal coating was done by Honeywell using conventional procedures. The board assemblies are bolted to the gyro base with appropriate supports and stiffeners to assure survivability in the 10,000 G launch shock environments. Three units with these board assemblies successfully passed cannon launch.

The concept for final gyro wiring and interconnect with guidance electronics has been defined but no specific effort was included in this contract to develop these processes. All interconnects will consist of two hardware cable and connector harnesses and one flex tape with thermal compression bond connections. One connector will bring out all detector preamp outputs and the second connector will bring out the shock wave

and impact sensor connections. All gyro interconnects and preamp power will be brought out on the flexible wiring cable.

Gyro Support Housing

In the new folded optics version of the CAB, the gyro support housing becomes integral with the projectile seeker housing. The conical outside diameter is part of the exterior surface of the projectile. The features and functions of the support housing are as follows:

- Radial bolt attachment to projectile electronics housing at aft end
- Axial bolting of the rotor and stator assembly and the torquer housing assembly
- Threaded mounting for the pickoff electronics and the shock wave sensors
- Gas distribution from gas bottles mounted in rear cavity for bearing levitation and spinup
- Auxilliary gas ports for testing of fully assembled seeker.

The gyro support housings fabricated on this program were machined from 6061 aluminum bar stock. Cost studies were performed, however, to consider alternate lower cost manufacturing techniques. Considerations were given to near-net shape forgings, near-net shape impact extrusions and near-net shape castings. All would require some secondary machining. Analysis indicates the most cost effective approach is a near-net shape casting using 356 T6 or 357 cast aluminum alloys. The proposed casting configuration is shown in cross section in Figure 7. As indicated, only two inside surfaces and the external surfaces would require machining.

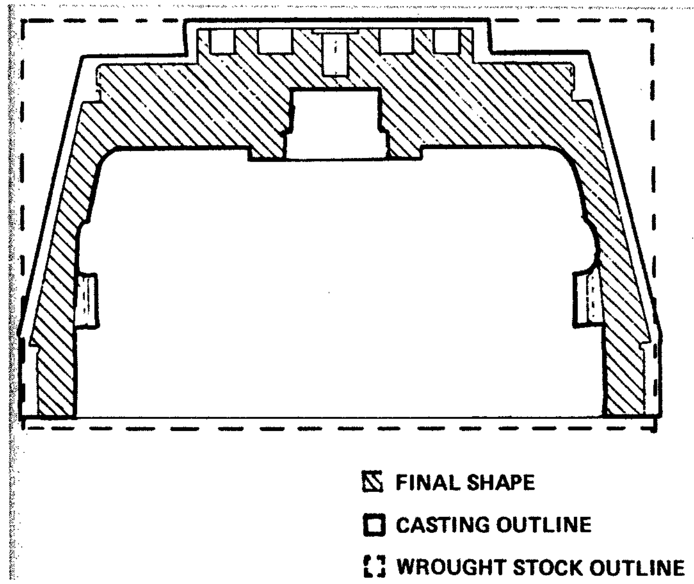


Figure 7

ASSEMBLY PROCESSES

The major thrust of the MM&T program in the area of the assembly of the CAB Gyro was centered in three critical areas:

- Compliant Bearing Molding
- Rotor Assembly Balancing
- Compliant Bearing Testing.

The Compliant Bearing Molding process is the single most important process in the CAB gyro concept. An elastomeric layer is bonded to the inside surfaces of the forward and aft rotor halves to form the hemispheric gas bearing cavities. This layer is molded in place using Ethylene Propylene Terpolymer (EPDM) rubber material. It is this compliant layer which enables the CAB gyro to survive the 10,000 g cannon launch without the need for a complex and expensive "gotcha" mechanism to absorb the shock. It is the compliant bearing molding process that generates the precision bearing cavity "as molded" without expensive grinding and lapping finishing processes normally associated with gas bearings.

The compliant bearing molding task consisted of the following elements: elastomer compound formulation and testing, mold design and fabrication, and molding process.

Extensive effort was expended to optimize the EPDM formulation for the compliant air bearing application. This effort was conducted at the Honeywell Defense Systems Divisions Materials Laboratory. The EPDM rubber compound was selected as the compliant layer elastomer because of its excellent compression set resistance, good flexibility at low temperature and low raw material cost.

The baseline EPDM formulation at the start of this program was reformulated. The development of the new formulation resulted in improvement in the following properties: moldability in multicavity mold, shrinkage, shelf life, and compression set.

The objectives of the multicavity mold phase of the MM&T project were as follows:

- Demonstrate that rotor halves can be molded independently
- Demonstrate that a multicavity mold is feasible
- Minimize amount of hand deflashing after molding

The mold design and fabrication was done by the Materials Laboratory at the Honeywell Defense Systems Division. Earlier programs had demonstrated the feasibility of molding a compliant bearing to the tolerances required using an engineering mold which produced one bearing at a time. Experimental gyros built with bearings from this mold have been tested and have demonstrated survivability after cannon launch.

The objectives of this program were to enhance the producibility and implement the changes required for the folded optics gyro design. The folded optics design required a reduction in bearing diameter. This scaling change was implemented without significant problems. The tooling concept selected was a 4 cavity mold, which molds two forward halves and two aft halves simultaneously. This size mold was compatible with our transfer press and it demonstrated the production concept. The same concept could be expanded to use larger size presses. The essential design of the mold is shown in cross section in Figure 8 showing one cavity of each type.

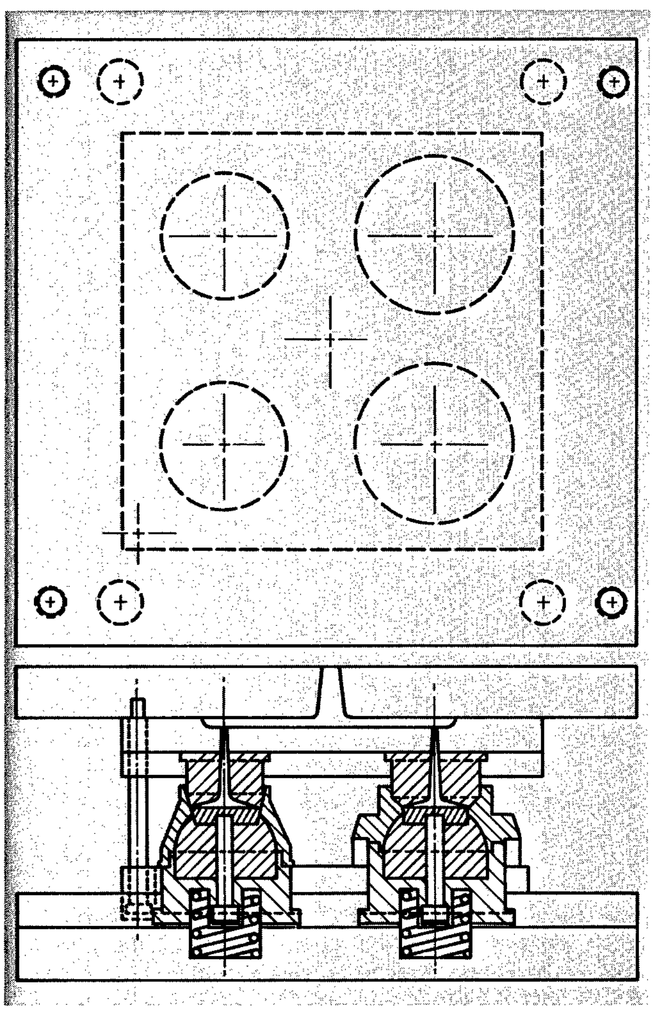


Figure 8

Several successful runs were achieved using this tooling. The need for some improvements was identified and should be incorporated in any follow-on effort. In early trials with the transfer molding spring pressure had to be increased to avoid leakage. These increased pressures resulted in distortions in the more flexible aft rotor halves. Ultimately, it was found that the spring force would have to be adjusted for each run because of variations in the geometry of one rotor half to the next. This is unacceptable on a production basis and a mold tooling change is needed. The best solution is to install expendable elastomer seals which would tolerate the variation in geometry and provide an effective seal at a lower spring force. Time and funding did not permit incorporation of this refinement on this program.

Significant improvements were made in the molding process as a result of efforts on this program. The most significant were: two step primer and adhesive system changed to one step primer, rotor halves molded independently, and shrinkage controlled by post vacuum baking of parts.

The original primer system used primer and adhesive applied to the grit blasted surfaces of the rotor in successive steps. The process was changed to a one part primer and adhesion testing was done to evaluate the peel strength of the two systems. The results indicate the suitability of the new process. The process time has been reduced with the one part system and the quality of the bond has been improved.

The mold design described in the previous section allows molding of rotor halves independently. This can be done by controlling mold tolerances such that the centerline of the spherical radii of each rotor half will coincide after assembly. Earlier engineering molds involved assembly of the two rotor halves around a spherical ball. This required more mold assembly and disassembly time. Loading of the new mold simply requires placing the halves on their mounting diameter. The aft rotors must be preheated prior to placing in mold. The mold design is such that the aluminum rotor halves fit line-to-line with the steel mold at molding temperatures.

Postcuring of the rotor halves is done after removal from the mold. The post cure is in a vacuum oven. The post cure removes the plasticizer, thus controlling shrinkage and stabilizing final sphere dimensions.

The balancing of the CAB rotor assembly cannot be done on conventional gyro balancing machines, because it is a "free rotor". Hence, the dynamic couple cannot be measured with force or velocity type sensors fixed to the balancer cradle. The wobble or dynamic couple must be measured optically using the mirror surface on the front of the rotor. Honeywell developed the concept for a CAB balancer with the American Hoffman Corporation in Lynchburg, Va.

The balancing concept corrects for wobble, or dynamic unbalance; it corrects for the static component (whirl) of the unbalance; and it corrects the static drift due to mass unbalance along the spin axis. The three corrections can be defined as follows (Figure 9):

(1) Adjust CG along spin axis to center of pressure.

(2) Adjust CG about spin axis to center of pressure.

(3) Adjust spin axis (principal axis of inertia) to be perpendicular to mirror.

A rotation of the CAB balance ring will change the balance along the spin axis. The balancing machine includes panel meters which tell the operator the amount of material to be removed from each balancing plane and at what angle about the spin axis. The two meters on the left show static balance corrections, and the two on the right show the dynamic balance corrections. The large meter in the center gives drift error in ten seconds when the button is pushed. The small meter in the upper center reads wheel speed in rpm.

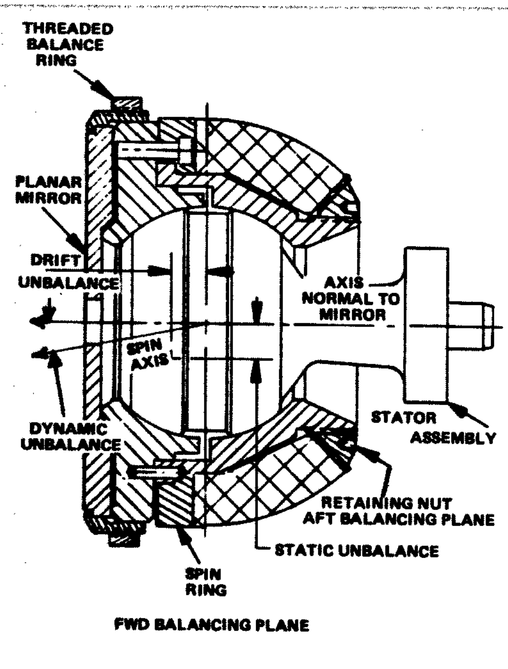


Figure 9

The sensing of the rotor mirror misalignment and drift comes from reflecting a laser beam off of the mirror on the front of the rotor. The reflected energy is received by a dual axis photodiode of high resolution. The outputs are fed to microprocessors which resolve the signals displayed on the panel meters. The static unbalance is sensed by a piezoelectric force transducer in the base to which the CAB assembly is mounted. Its output is also resolved by a microprocessor and displayed on the panel meters.

Experience has shown that rotors can be balanced in less than fifteen minutes. In production a fully trained operator is expected to average about 10 minutes per gyro. Other features of the equipment include controls for pressurizing the bearing and for rapid spin-up. The speed of the rotor is controlled by its own hero engine nozzles. There is a mechanical caging system for aligning the rotor spin axis prior to spin up. An electric drill is provided for precise removal of material to accomplish the balancing. Drill diameter and depth determine the mass removed. The rotor is stopped by hand when making a correction; however, bearing gas is left on to assure no contaminant can get into the bearing.

The quality of the molded cavity and the sizing of the stator ring are evaluated in terms of bearing performance after rotor and stator assembly. Four tests are made which assess the quality of the bearing as follows:

- Minimum liftoff pressure
- Operating pressure
- Radial bearing clearance
- Rotor terminal speed

All testing is done in one fixture and involves mounting the stator in the fixture and attaching the gas hose from the pneumatic test console.

The minimum lift-off pressure test is a good measure of the uniformity of the compliant layer and the cleanliness of the bearing surfaces. The test is accomplished by slowly opening the bearing gas valve on the pneumatic console and recording the minimum pressure at which rotor is observed to be floating free in all attitudes without observable restraint. The gas pressure is displayed on the gage in the pneumatic console.

After completing the minimum pressure test, the bearing gas valve is opened further until the bearing orifices and clearances are proper.

Bearing radial clearance is checked using a low contact force indicator, such as a Federal microprobe, by placing the indicator contact on the spin ring. The change in indicator reading is measured between gas on and gas off.

The final check involves letting the rotor run until the hero engine no longer accelerates the rotor. The terminal speed is measured using a conventional strobe light. Terminal speed is a measure of the bearing clearance and hero nozzle sizes.

In production, it is estimated that the entire test sequence can be accomplished in about 2 minutes.

Pilot Production

The Option I portion of this project involved the build and test of eight CAB gyro subassemblies. The build and test of these assemblies was accomplished with the following objectives in mind:

- Demonstrate the improved processes
- Document a baseline production build process
- Document a baseline inspection and test plan
- Establish document control system and traceability plans.

The pilot production program was conducted in Honeywell's Engineering Tactical Gyro Lab utilizing engineering technicians. Process engineers worked with the technicians in developing and documenting all processes. Inspection was done by the Honeywell Product Assurance organization in accordance with standard Honeywell procedures. The gyro testing was performed as an informal acceptance test conducted by test engineers who also developed the procedures and documented the data system. The semiautomatic engineering test equipment was designed and built by Honeywell.

Gyro Assembly Build

Eight gyro assemblies were built, and the simplicity of the design allowed assembly of these gyros without any special tooling. It is recognized, however, that future production build involving larger quantities will generate the need for some special holding and storage fixtures.

Final inspection of these gyros was completed on the follow-on contract which included integration with the optics and detectors. This postpones final conformal coating of the pickoff electronics, thus maintaining a degree of flexibility if further gyro testing should indicate the need for rework.

Gyro Testing

Gyro testing was done at the Gyro Subassembly stage in accordance with requirements of the specification. This is intended to be a production check of performance prior to integration of the optics and detector preamp assembly. This check includes the following tests and calibrations.

- Impedances
- Mirror alignment
- Pickoff scale factor/linearity
- Torquer scale factor/precession rate
- Static drift and elastic restraint
- Spinup, wheelspeed, and uncage error
- Static and G-sensitive drift.

Follow-on Work Suggested

Because of the success of this program, Honeywell strongly recommends that the CAB gyro seeker be funded as a Production Improvement Program (PIP) on the Copperhead program.

This program would include flight demonstration tests and qualification tests and prepare the CAB for a low rate initial production program. The front end of the PIP program should include some development funds to complete tasks not included in this program as follows:

- Complete development of gas bottle and regulator
- Complete development of interconnect between gyro and guidance electronics

Further effort is also warranted in the area of follow-up MM&T tasks aimed at further cost reduction and process development. These tasks would include:

- Development of near-net casting for gyro support housing
- Development of LSIC chip for gyro pickoff electronics
- Redesign of multi-cavity mold to improve yield
- Fully automate gyro testing.

Multifaceted Facility Built

Production of Infrared Detectors

RICHARD BRADY is a Project Leader in the Electronic Warfare Systems Division of the U.S. Army Electronic Warfare Laboratory, Ft. Monmouth, New Jersey, where he has worked on electro-optical projects for the past five years. Prior to this service, he spent eleven years in electro-optical work at the Combat Surveillance and Target Acquisition Laboratory at Ft. Monmouth. He joined the Government service in 1968 after receiving his M.S. in Physics from Fairleigh Dickinson University. He earlier received his B.S. in Physics from Brooklyn College.

Photograph Unavailable

Groundwork for higher rate production of infrared detectors of laser energy for laser warning receivers was laid upon completion of a recent AVSCOM mantech project. The Electro-Optical Division of the Perkin-Elmer Corp. undertook a program to develop manufacturing methods and techniques for producing interdigitated Indium Arsenide (InAs) detectors at a rate of 50 detectors per 40-hour week. Funded by the U.S. Army Aviation Systems Command and monitored by the U.S. Army Electronic Warfare Laboratory (ERADCOM), this work also involved a pilot production run and the design of a specific facility to build the detectors.

The detector array consists of two pairs of interdigitated comb-like photovoltaic elements formed by diffusion and mesa etching in an InAs wafer. Each comb element consists of nine parallel bars each 0.225 mm wide x 5 mm long. The bars of one comb are arranged alternately with the bars of the other comb to form an interdigitated structure. The detector chip is mounted on a standard integrated circuit header such as TEKFORM 8128.

During the course of the program, three sets of three engineering samples each and a set of eight confirmatory samples were delivered and the production rate was demonstrated through execution of a pilot run of 25 detectors.

Mesa Type Devices Chosen

At the onset of the program, two types of device structures were pursued: mesa and planar. The starting material in both cases is n-type single crystal InAs purchased in wafer form. For both types of devices, p-n junctions are formed by the diffusion of zinc into the InAs with the diffusion carried out in an evacuated, sealed quartz ampoule. For the mesa structure, the detector bar pattern is formed by etching mesas through the p-region and the p-n junction. For the planar structure, a deposited and suitably patterned silicon dioxide or silicon nitride film is used as a diffusion mask to form the detector bar pattern during the diffusion.

While ultimately the planar structure would be the preferable approach, being inherently passivated, comparison of performance data measured on both types of devices fabricated during the program showed that mesa-type devices generally outperformed the planar devices. Consequently, the decision was made to limit the remainder of the effort to the fabrication of mesa-type devices.

NOTE: This manufacturing technology project that was conducted by Perkin-Elmer Corp. thru the U.S. Army Electronic Warfare Laboratory was funded by the U.S. Army Aviation Systems Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AVSCOM Point of Contact for more information is Bill Brand, (314) 263-3079.

The first set of engineering samples employed off-chip interconnects as shown in Figure 1. The specification calls for the output of the two combs to differ by not more than 10 percent when the device is scanned with a 1-mm-wide slit oriented perpendicular to the detector bars. With standard metallization, the resistance of the contact bars is high enough to cause the output signal of a detector to drop by as much as 30 percent when the illuminated area moves from the contacted end to the opposite end of the comb. In order to meet the matching criterion, one had to connect/interconnect all comb elements on the same side.

Introduction of a thick gold electroplating process which allowed 25 micron wide and 6 micron thick gold to be plated onto the evaporated contact bars reduced this signal loss to less than 4 percent. This led, in turn, to an improved mask design and the device shown in Figure 2.

The improved mask design resulted in better uniformity of detector response, higher average responsivity and, last but not least, it reduced the number of bondwires from 36 nonredundant ones to 4 pairs. The improved mask design was introduced with the second lot of engineering samples and used throughout the remainder of the program. A cross section of the device indicating the major process steps is shown in Figure 3.

Work Transferred to New Facility

Between the second and the third lot of engineering samples the activity was transferred from Perkin-Elmer's research facility to the newly constructed detector facility, ensuring that a significant portion of the program be conducted in a typical manufacturing environment. This transition implied that all the processes be executed on new and different equipment and in a production-oriented facility rather than in a research laboratory. Furthermore, the effort conducted through the second lot of engineering samples utilized cleaved wafers with the diffusion carried out in small 100 cubic centimeter ampoules, while in the new facility 38-mm diameter wafers were used and the diffusion was carried out in 1500 cubic centimeter ampoules. The switch to 38-mm wafers resulted in a less labor intensive fabrication (each wafer contains 8 detector chips) and allowed the introduction of batch processing methods.

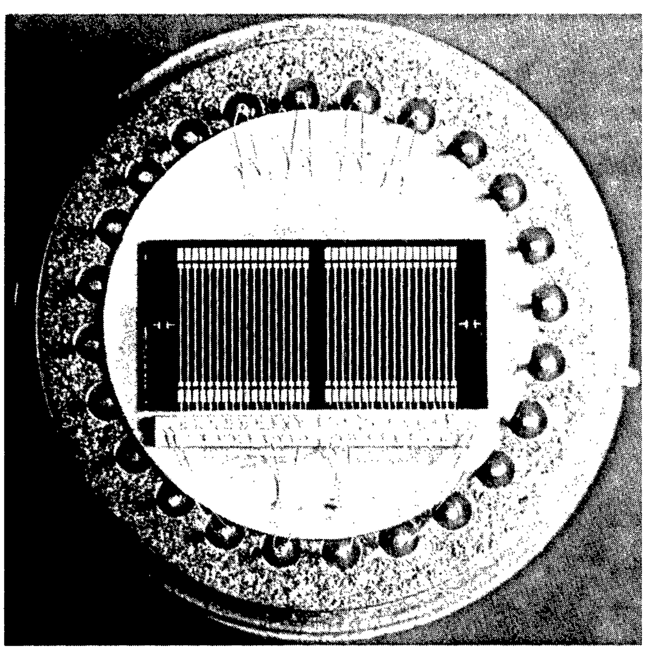


Figure 1

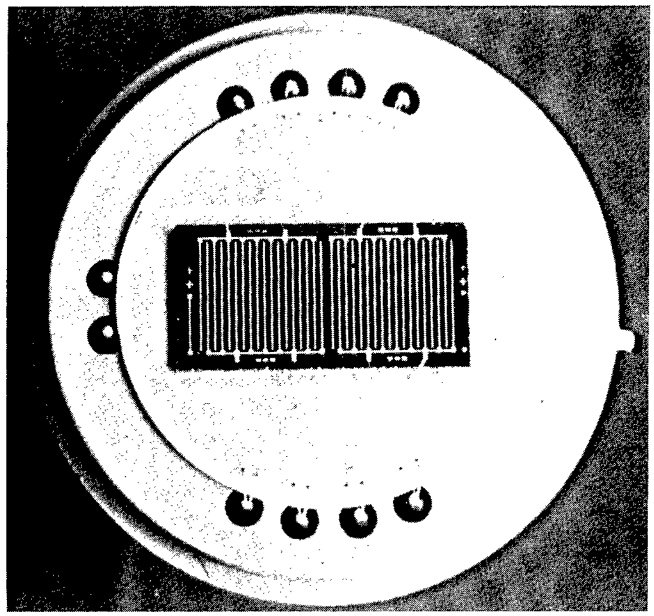


Figure 2

Test data acquired on detectors fabricated from starting materials of different carrier concentrations indicated that responsivity, crosstalk, and rise time vary significantly with carrier concentration. The zero-bias impedance of the devices is, obviously, also affected by the doping level of the substrate. Using the performance parameters measured on detectors fabricated through the second lot of engineering samples, one can relate detector performance to carrier concentration.

With the fabrication of the third lot of engineering samples, process run sheets were introduced to allow an easy and reliable monitoring of each diffusion run. Also, three lots of three engineering samples each and three separate test reports were delivered during this phase of the program. These reports present both raw and reduced data on zero-bias impedance, I(V) characteristic, responsivity at three wavelengths, specific detectivity D*, rise time, crosstalk, responsivity matching, uniformity of response, and isolation resistance.

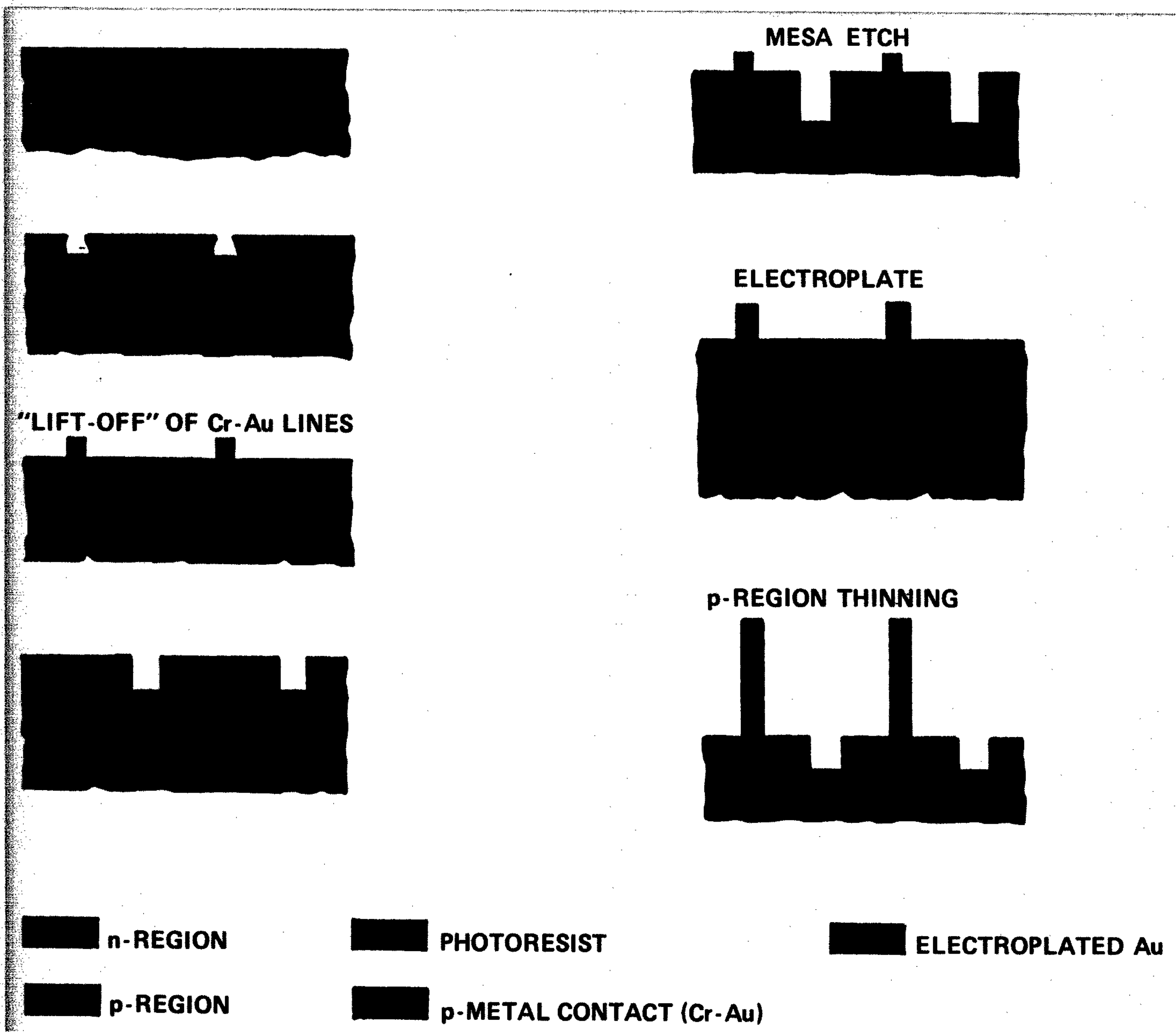


Figure 3

Confirmatory Samples Produced

Authorization to proceed with the fabrication of the confirmatory samples was received after acceptance of the second lot of engineering samples. The starting material used for the two diffusion runs providing wafers for these samples came from four different ingots. In addition, within the same ingot, wafers from both the seed and the tail end of the ingot were incorporated in an attempt to gather data on a range of starting material parameters which one might expect from MCP, the supplier of InAs wafers.

The eight confirmatory samples were selected from 24 packaged devices fabricated during this phase of the program. To assess the reproducibility of the process the mean standard deviation and maximum and minimum values of six of the measured parameters were determined for the eight confirmatory samples. The relatively narrow spread of the data indicated that the processes were under reasonable control and, therefore, appropriate for the pilot run.

Pilot Run Successful

A production rate of 50 detectors per 40-hour week was demonstrated through execution of a pilot run of 25 detectors. The fabrication process of the interdigitated InAs detectors can be broken down into 33 distinct process steps and the final electrical/optical test of the completed devices. The process flow is depicted in the flow chart for InAs detectors (Figure 4). To properly size the number of wafers required to yield at least 25 detectors, it was assumed that each wafer would yield only one acceptable device. Furthermore, to gain experience in batch processing, the number of wafers per diffusion run was increased from the eight used for the confirmatory samples to 15. Thus, the entire plot run was accomplished through two diffusion runs.

The large ampoule diffusion was introduced with the third lot of engineering samples. The process incorporates a bake-out of the loaded ampule while it is still on the ion pump. Diffusion Run No. 1 was in many respects an experimental one and also used to establish the appropriate bake-out temperature and time.

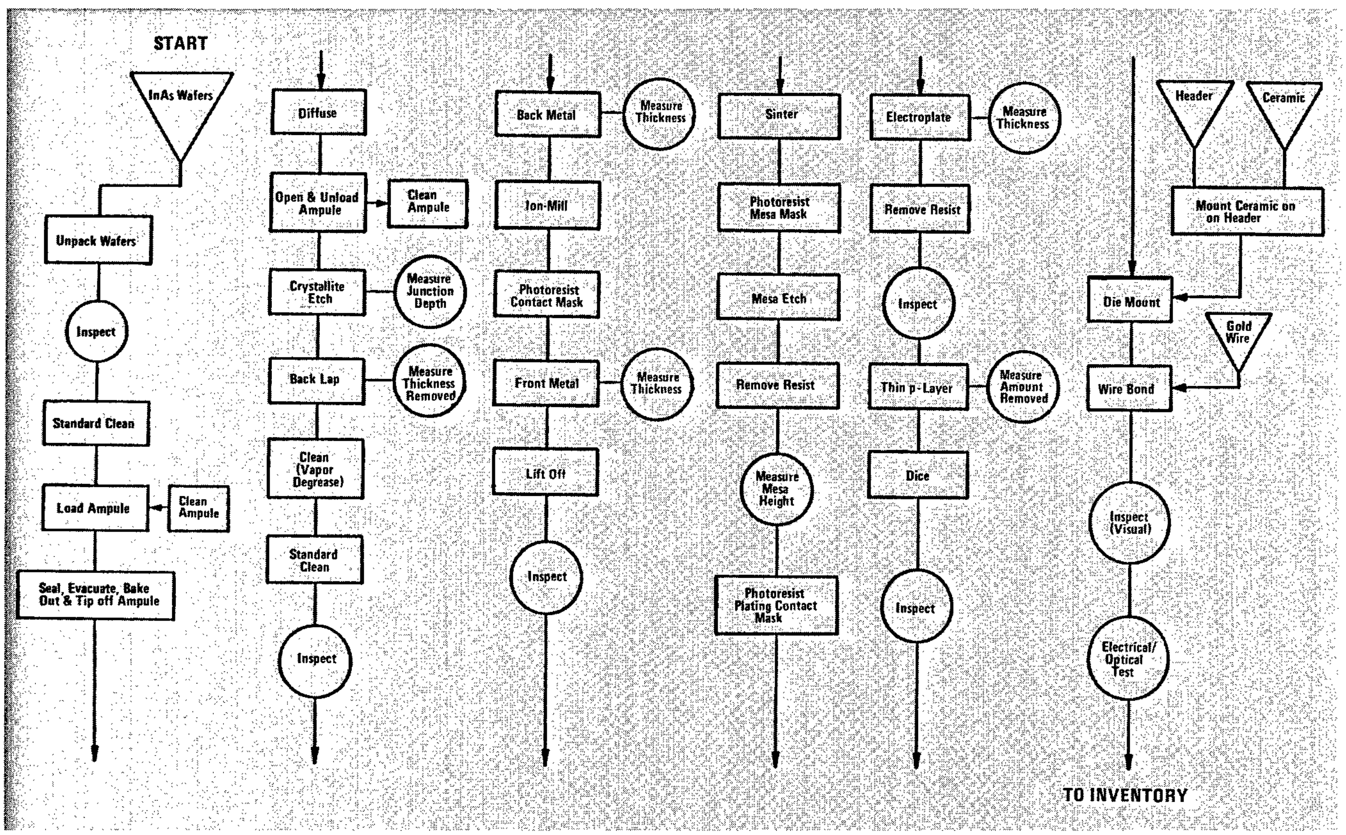


Figure 4

Thus, the diffusion depth attained in Run 1 does not fall in the pattern of all other diffusion runs. All diffusions were carried out at 480 C, the zinc arsenide charge was kept at 640 micrograms per cubic centimeter of ampoule volume, and the total insertion time in the furnace was monitored rather than the time at temperature. Inspection of the data indicated that there was a time difference of 50 minutes between insertion time and the actual diffusion time.

Inspection of the data shows that the diffusion velocity of 5 of the runs varies by about 22 percent. Of the total of 168 chips after dicing, 138 chips were die bonded and 30 were reserved in chip trays for future use; 130 chips were wire bonded and entered final electrical/optical test. Of the 130 devices tested, 86 met all acceptable criteria.

Of the 86 accepted devices, 25 were selected as pilot run samples. On all of the devices the following parameters were measured: zero-bias impedance, isolation resistance, rise time, responsivity, responsivity matching, cross-talk, uniformity of response (both difference and variation), and specific detectivity.

Final Evaluation Not Conclusive

During the initial test of the 130 packaged devices, 52 failed because of low zero-bias impedance and a soft I(V) curve. Subsequent experiments indicated that the junction deterioration did not occur during die or wire bonding. A soft I(V) characteristic and, thereby, a low zero-bias impedance can be caused by at least two mechanisms: dangling bonds and/or inversion layers. To test this argument one device was treated with AB etch, the etch used for both mesa etch and p-layer thinning, for less than one second; this treatment restored the I(V) characteristic and also improved most other parameters. The AB etch has an etch rate of about 1300 angstroms/sec and, thus, can reduce the p-layer thickness to the point where one loses most if not all responsivity.

After this initial experiment, the remaining 51 devices which had failed because of low zero-bias impedance received the AB etch treatment and were retested. Eighteen of the total of 52 devices met all specifications after AB etch. The 22 devices which did not pass had a thin p-layer to start with; the treatment created excellent diodes with very low responsivities. The outcome of these experiments restricted the introduction of a soft I(V) curve to the process steps between mesa etch and demounting after dicing.

While the present fabrication process is acceptable for production, it would be desirable to eliminate the post-assembly cleanup etch and the associated retest. Exact identification of

where the soft I(V) characteristic is introduced and how this effect could be avoided or counteracted was not possible during this effort and will have to be accomplished at a later time.

Using the labor and yield data of three runs, a production rate of 60 devices per 40-hour week was established. This production rate was limited by the dicing operation.

Detector Facility

The detector facility is a 7,500 sq. ft. one-story building which was designed to accommodate the fabrication of several types of detectors and optical filters. The variety of products to be handled in one facility resulted in a functional rather than an in-line layout (Figure 5). The facility consists of six functional areas:

Photolithography	(497 sq. ft.)
Chemical/Vacuum	(1092 sq. ft.)
Furnace	(619 sq. ft.)
Lapping/Dicing	(320 sq. ft.)
Assembly and Test	(841 sq. ft.)
Entry/Change/Storage	(256 sq. ft)
Total Working Area	(3625 sq. ft.)

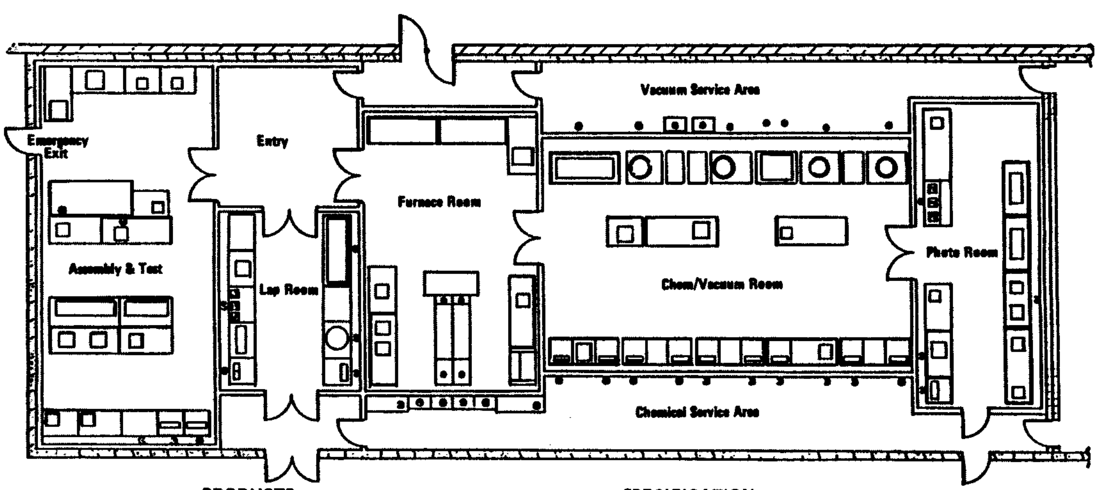
Chemical and vacuum service areas and HVAC occupy the remainder of the building. All working areas are maintained at 70 degrees plus or minus 2 degrees F and 35-40 percent relative humidity and are class 10,000 clean rooms but for the lapping/dicing area, which is class 100,000. All critical operations are carried out under class 100 vertical laminar flow hoods.

Several major pieces of equipment are utilized in this facility. In addition, there are ten custom designed chemical stations and a Perkin-Elmer built ampoule exhaust and seal-off station. Ancillary equipment such as microscopes, probe stations and curve tracers, dessicator cabinets, ovens, and a Tencor Alpha Step 200 Profilometer are placed at strategic locations.

Process Looks to Refinements

The processes developed during the engineering and confirmatory sample phase of this work were found to be repeatable and suitable for batch processing encountered during production. Further, the overall layout of the detector facility and its equipment and tooling met the anticipated production rate requirements, and the attained overall yield of 32.7 percent exceeded the original estimate by a factor of 6.5. A production rate of 60 detectors per 40-hour week was demonstrated; this rate would require a staff of six operators plus supervision.

However, while the process meets all requirements, it would be desirable to eliminate the post-assembly cleanup etch and the associated retest. This will require an additional effort to identify where the soft I(V) characteristic is introduced and subsequently introduction of the process changes required to eliminate the effect.



PRODUCTS

- Detectors – InAs, Si, $LiTaO_3$
- Etalons – Mica, Si

SPECIFICATION

- Area: 3,625 ft^2
- Class: 10,000
- Class 100 for Critical Operations
- Environment: 70 F ± 2, 40% RH + 0, -5

Figure 5

In-Process Testing the Key

Large Scale Hybrid Rework Reduced

Manufacturing problems related to the excessive physical size and complexity of large scale hybrid microelectronics have been substantially improved by a recently completed U.S. Army Missile Command manufacturing technology project. The work performed by General Dynamics' Pomona Division successfully established the manufacturing technology needed to design, fabricate, test and rework large scale hybrid microcircuits with cost effective yields. This technology features the use of bumped tape bonded to integrated circuit chips in order to permit electrical testing of the chips prior to assembly on the multilayer substrate.

The fact that the bumped tape automatically bonded beams are substantially stronger (average 40 to 50 grams pull test) and always are prealigned again offers a potentially more reliable bond and less rework of wire bonds. In high volume production this will be significant.

It is recognized that the bumped tape aspects of total large scale hybrid processing are in their infancy and will be evolving in its maturity over an extended period of time. The other aspects of the process including items such as the engineering design, substrate processing, and fault isolation have made reasonable yields possible with relatively conventional techniques, with the bumped tape approach providing extra benefit.

Special LSH Problems

Large Scale Hybrid devices are defined as having a substrate area greater than 3.6 square inches, requiring a multilayer thick film metal interconnection, containing in excess of 30 active devices (primarily integrated circuits), and being in a hermetically sealed metal package.

Large hybrids have manufacturing problems not normally encountered in their smaller counterparts. Most of these problems are related to physical size, as larger areas permit the use of more integrated circuits; this results in greater circuit complexity and increased probability of component and interconnect failures, with correspondingly decreased hybrid level yields and increased fault isolation and rework. The emphasis of the work performed in this project was to introduce technologies for in-process functional testing and improved fault isolation.

Consideration was not given to system design or partitioning of large scale hybrids. Work was concerned wholly with manufacturing and testing of large scale hybrids and those aspects of design bearing upon their producibility.

PAUL WANKO is a Project Manager in the Manufacturing Technology Division, System Engineering Directorate of the Army Missile Laboratory, U.S. Army Missile Command. After graduation from Pennsylvania State University with an Associate degree in Engineering, he came to Redstone Arsenal while working for the Navigation Division of the Bendix Corporation as a field representative on the PERSHING Missile System. He began working for the Guidance and Control Directorate of the Army Missile Command in 1965 as a packaging designer and since has contributed to the designs of many Army missiles and launches. In 1970 he headed up the Hybrid Microelectronics Design Group in support of the new Hybrid Laboratory at the Missile Command. A few of his hybrid microelectronic designs are Range Safety devices, Detector Preamplifiers and Missile Auto Pilot. He is currently managing several MM&T projects and is responsible for the progress and reporting of these projects. He is a member of International Society for Microelectronics, Huntsville, AL chapter.

NOTE: This manufacturing technology project that was conducted by General Dynamics' Pomona Division was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Paul Wanko, (205) 876-5619.

Topics Covered

A general industry survey was made of problems encountered in the manufacture of large scale hybrids. Solutions were proposed for those problems identified, processes were developed, and they were tested by building hardware.

Design considerations were limited to the substrate layout. Design standardization of the integrated circuit bonding areas on large scale hybrid substrates is required to implement recommendations for pretesting the integrated circuits.

Description of the fabrication processes for large scale hybrids was divided into three major processes for convenience: these were (1) substrate manufacture, (2) integrated circuit pretest including the application of all bumped tape automatic bonding operations, and (3) hybrid assembly and test.

Each of these fabrication processes has its own specific test requirements. They collectively contribute to successful testing of the completed hybrid; therefore, it was decided to include the investigation and solution of testing problems as separate parts of the fabrication processes' discussions rather than consider them independently. Similarly, rework was also addressed as part of the individual fabrication processes.

Processes Evolving Continually

The conclusions reached by MICOM and General Dynamics at the end of the project were as follows:

- In-process functional testing of integrated circuits can substantially improve first functional electrical test yield.

- Chip testing must exceed circuit level requirements in order to be effective.

- Because of total large scale hybrid complexity, rapid large area testing and fault isolation still are very significant to ultimate yield percentage.

- Secondary bumped tape automatically bonded benefits of lead bond reliability offer significant advantages.

- Large scale hybrid manufacturing process development for producibility upgrading is in a state of evolution which will continue to improve the process.

For improved producibility of large scale hybrids the bumped tape approach was demonstrated to be applicable and effective in pretesting the entire range of integrated circuit chips employed in this project. It was recognized that if customized test program software was created more exactly to reproduce the actual circuit operating conditions—as opposed to the more generic standard test programs—chip reliability at the hybrid functional test level could be further optimized. This was the recommended approach and the objective for production process evolution.

Two Phase Effort

The task was structured into two phases. The basic effort (Phase I) established design guidelines, materials, part standards, qualification procedures, fabrication processes, test and fault isolation techniques, and rework procedures. Phase II demonstrated through hardware build and test the producibility of the basic effort processes and procedures.

Phase I Objectives

- Verify Key Requirements for Large Scale Hybrid Manufacturing Process Development

- Conduct Industry Survey

- Establish Design, Fabrication and Test Guideline

- Formulate a Conduct of Program Plan

Analysis of the industry survey coupled with the background and experience that existed at General Dynamics verified that the trend in military hybrid microelectronics industry was toward substrate complexity and circuit line density, which exceeded present production standards by a factor of between 4 to 10 times.

In-process testability of integrated circuits to assure virtually 100 percent use of good components, particularly large scale and medium scale integrated chips, was considered a key element of cost effective large scale hybrid production.

Expeditious fault isolation and repair procedures for their overall hybrid circuits, upgraded centrifuge and leak testing at the package level, and ability to handle resistor and capacitor chip components were also identified as significant requirements.

A comprehensive manufacturing process development program was formulated to improve large scale producibility. It featured upgraded substrate design layout, application of bumped tape automated bonding (BTAB) for functional in-process IC testing and lead bonding, thick film substrate circuit technology, and hybrid level testing.

Phase II Objectives

- Demonstrate the Process Technologies
- Build Demonstrational Prototype Hardware
- Perform Functional and Reliability Testing
- Document Program Conduct and Process Results

Individual technologies identified in the large scale hybrid producibility guidelines were demonstrated with various test samples and engineering prototype design hardware. Ten mil lines, 12.5 mil diameter vias with 150 vias per dielectric layer for 4-6 layers can be produced with greater than 60 percent initial yields.

The application of bumped tape integrated circuit carriers coordinated with plastic slide test beds was demonstrated to be applicable for complex logic cell array and microprocessor integrated circuits as well as other integrated circuit chips.

In-process functional testing was demonstrated for these integrated circuits. Hybrid screening test showed hybrid g load tolerances of 5000 g in centrifuge testing. Twenty psi absolute was shown to be the maximum allowable pressure for helium leak testing.

Forty hybrid test samples were prepared for reliability testings. These samples were subjected to various time-temperature histories and evaluated for interconnection reliability.

Twelve complete large scale hybrids on 3.6 sq. in. substrates, 6 conductor layers, 31 integrated circuits (including operational amplifier, LCA, microprocessor, ROM, and RAM chips) and 98 total electronic components were fabricated. These hybrids, which were built to engineering design and fabrication standards, were tested for full electrical functional performance.

Oversize Hybrids Limited

One of the first tasks undertaken as part of the Large Scale Hybrid contract was a survey of military hybrid microcircuit manufacturers in order to obtain information regarding large hybrid design, substrate fabrication, assembly, test, and rework procedures.

While our survey did not disclose any consensus as to large scale hybrid construction details, we noted a reluctance to build microcircuits on ceramic substrates with areas of four square inches or more in a single cavity package. Difficulty in achieving hermetic seals, package flatness and strength, as well as difficulty in meeting MIL-STD-883 screen test requirements were the primary factors in the preference for smaller circuit assemblies.

Testing and fault isolation on a large microcircuit present problems due to the sheer multiplicity of electrical functions which are present. In addition, the mathematical probability of a large number of devices on a single hybrid all functioning properly is quite low unless the failure rate of the individual device is near zero percent. Inferences based on the survey indicate that the two most prevalent approaches to the problem of increasing large hybrid microcircuit electrical test yields are the use of ceramic chip carriers and tape bonding. Incoming chip probing is also used by some companies.

Manufacturing Considerations

One of the major driving forces in this manufacturing technique investigation was the improvement of the first functional test yield by providing tested integrated circuit chips for assembly into the hybrid circuit. Application of the bumped tape integrated circuit chip carrier and associated plastic slide chip handler and test substrate are the key elements which permit achievement of this objective.

Any large hybrid will have many discrete parts which are not integrated circuits and which do not lend themselves to the tape bonding approach. These are the resistors, capacitors, and diodes. Each of these has a finite probability of failure which will prevent a first functional test "pass" as surely as a defective integrated circuit. Therefore, specialized probe cards were designed to contact the fully populated multilayer thick film circuit in the open package. Planarity is of crucial importance for a large array of probes since in these circuits as many as 400 nodes may be probed simultaneously.

Loads Critical

The centrifuge and seal testing phases of the MIL-STD-883 hybrid microcircuit screen test procedures presented the most serious problems for large hybrid microcircuit production. Even a slight amount of bending or flexing during centrifuge testing or pressurization prior to fine leak testing could cause damaging peel stresses on the substrate package bond or "oil-can" the package lid, resulting in hermeticity failkure or shorting of the internal components. In some cases, a 500 g centrifuge test could destroy the entire hybrid. Without special strengthening of the package lid, resulting in hermeticity failure or shorting of the in area in normal kovar enclosures survive a 10,000 g test. This

occurs despite the fact that the tensile strength of the substrate-to-package adhesive has not been exceeded. For hybrid microcircuits greater than about one square inch in area the traditional leak test and centrifuge procedures used for hybrid circut manufacture are not useful process screens.

Design Criteria

When considering the development of large hybrids, the most important attribute is reduction in volume. Since volume is the limiting factor and less than 10 percent of the area occupied by discrete components is taken by the functional element itself, input/output and interconnection consumes the major fraction of the circuit area. Thus a single large hybrid generally is preferred over many smaller hybrids because of its greater interconnection density.

Interconnection Requirements

Since every available interconnection to a chip must be made, the footprint pattern (4mm, 5mm, etc.) selected will provide the required number of "feet" to make all available interconnections to the chip.

Using every available interconnection to a chip may result in some interconnections which are not electrically functional in a given circuit; however, since each chip type may be connected differently from circuit to circuit, all chip level pads must be contacted. As a result, the pad pattern on the substrate must allow for attachment of nonactive leads. These interconnections are retained for potential added circuit requirement and multiple use over many programs.

Figure 1 illustrates a chip with 46 interconnections used with a footprint with 52 leads ("feet").

Thick Film Planarity A Challenge

Large scale hybrid substrates are particularly prone to nonplanarity due to the large area. This makes the problem of laying down uniform screened layers more difficult; therefore, tight control must be exercised at incoming inspection of substrates.

The process of building up a thick film substrate with alternate layers of conducting and nonconducting materials has inherent in its concept the possibility of nonuniform thickness. As more layers are added to the substrate any variations in thickness are additively accumulated. This can lead to a resulting surface which is nonplanar. If planarity is not maintained under control, all subsequent operations are more difficult, if not impossible.

Multilayer Considerations

With large scale hybrids we have to deal with many more layers of conductor and dielectric. This is due to the increased number of components and the consequent need for interconnections within the hybrid. It is not uncommon for there to be

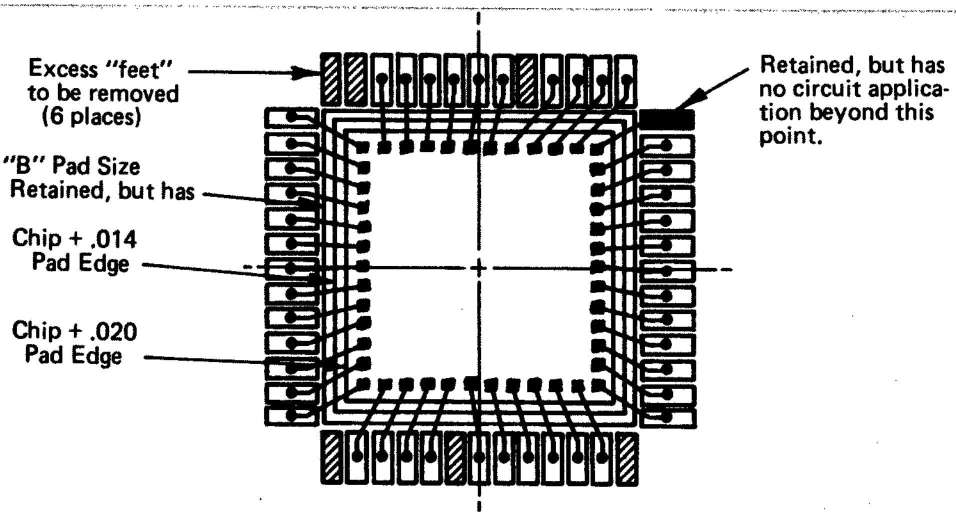


Figure 1

up to 10 to 12 layers (5 or 6 conductive layers); and, of course, there are many more interconnections between layers. All of this complexity leads to the opportunity for manufacturing and design errors to creep in. It is imperative that these substrates be thoroughly tested prior to assembly. Errors must be caught as early as possible in the manufacturing process while value added is the lowest.

The required measurement is simply circuit path conductivity (shorts and opens). Also, substrates may have thick film resistors which must be checked and trimmed to the right value as well.

It is hard to appreciate the number of nodes which may have to be checked in a large substrate. Some large substrates have upwards of 400 nodes. It is necessary to use a programmed substrate tester to perform this operation, as the number of individual tests required precludes manual testing.

It is impossible to check all possible situations so typically only a few thousand are considered. A second characteristic of these nodal arrangements is the frequent necessity to probe very closely spaced positions. Probe cards with as many as 400 probes spaced closely together are not available; therefore, the option chosen is to use smaller probe cards with fewer probes and test sections, perhaps quadrants, independently. This practice has the effect of testing four areas but not testing interconnections between the areas.

Rework Subjective

As a policy, thick film substrates should not be reworked after firing. Due to the cost factor in building large area, multilayer thick film patterns on large substrates the rework must be shown to be cost effective as opposed to scrapping the substrate and initiating a new fabrication start.

Figure 2 represents th process flow which General Dynamics Pomona is presently utilizing during large scale hybrid fabrication.

Pretest Process Development

The flow chart shown in Figure 3 represents the various operations associated with the mating of bumped tape to integrated circuit chips and the subsequent testing and disposition of these leaded chips. A proposed bumped tape work center in which these flow chart functions could be performed in an efficient, coordinated manner is shown in Figure 3, also.

In referring to the flow diagram we see that the initiation of activity in the work center requires an input of materials which,

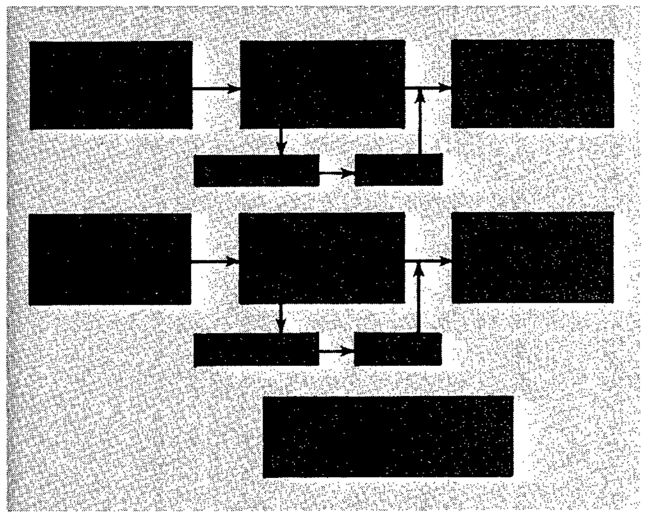


Figure 2

in the far left block of the flow diagram, is labelled 'BTAB MACROKIT SUPPLY." Typically, this kit would contain a large number of IC chips of a given chip type along with sufficient, compatible tape.

Thus far a measuring microscope has been used as the inspection tool (Figure 4); tape quality is examined in accordance with criteria established during earlier work on a Navy bumped tape contract.

The carriers (Figure 5a and 5b) (Lexan-Polycarbonate per Federal Specification L-P-393a) act as the storage and test vehicles for the lead formed chips.

Process Tests and Evaluation

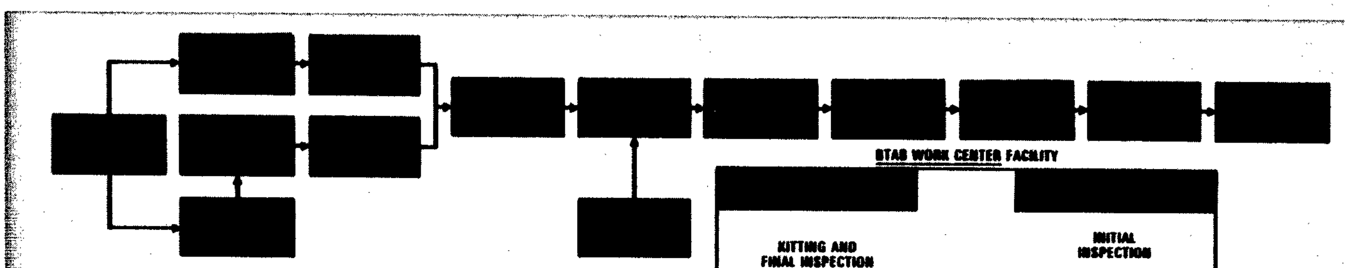
The reliability of the bumped tape chips is directly related to the quality, uniformity, and integrity of the ILBs and the formed leads; therefore, the performance of the ILB machine and the excise and form machine are crucial in chip-to-tape assembly. Figure 6 shows a chip test fixture.

Process Specifications

The specifications for large scale hybrids are in essence the same as those used for standard smaller hybrid microassemblies. Two notable exceptions for circuits using bumped tape assembly techniques involve outer lead bonding of the leads of the bonded device to the substrate footprint and rework and repair of bumped tape mounted chips. Process flow is presented in the accompanying flow chart (Figure 7).

Producibility Hardware Varies

There are two types of demonstration hardware: fully functional units and reliability demonstration hardware in which the



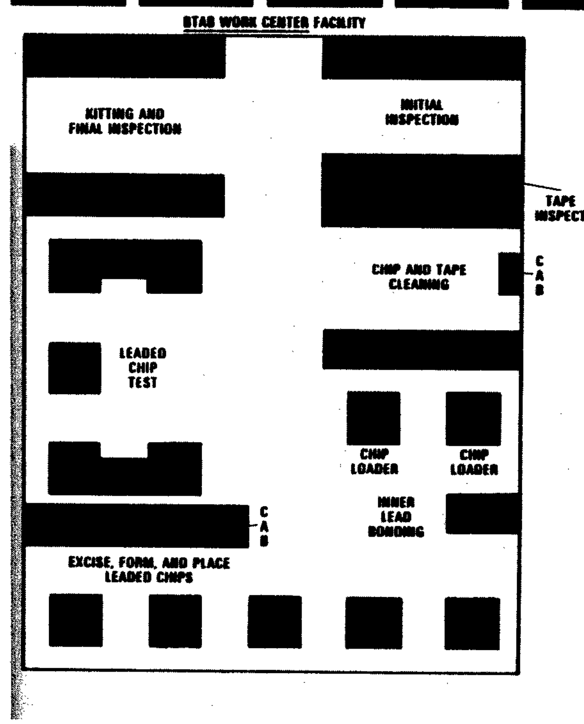


Figure 3

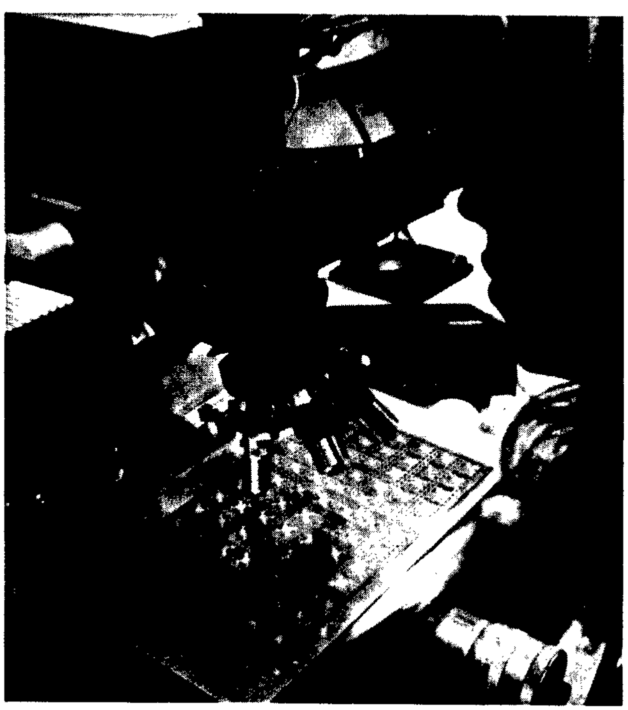
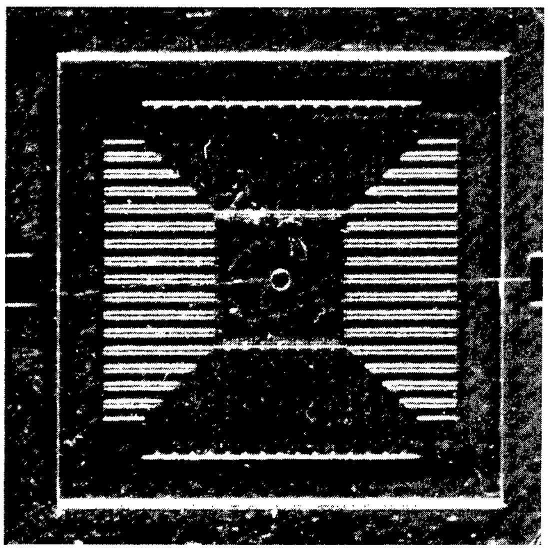


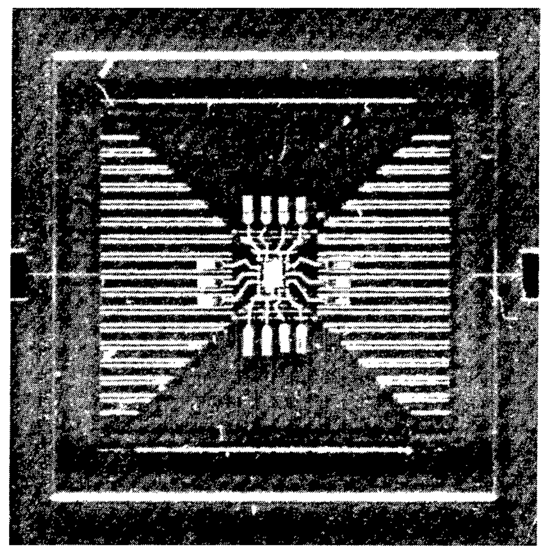
Figure 4

viability of the large scale hybrid processing is assessed. The reliability hybrids were constructed on the same multilayer substrate and enclosed in the same package type as the functional circuits. These substrates are populated with thirteen integrated circuits having tape lead connections between the device bonding pads and the substrate, while four IC's are bonded with 1 mil gold wire bonds. Also, there are 12 resistor chips, wire bonded, and six capacitors. The reliability hybrid is shown in Figure 8. The wires visible on the left side of the substrate serve to connect the operational amplifiers directly to the package pins in order to permit testing of these devices without removing the package lid. Each circuit is composed of 292 tape bonded leads and approximately 300 wires.

The second type of demonstration hardware consisted of twelve circuits which are identical to the final engineering



(a)



(b)

Figure 5

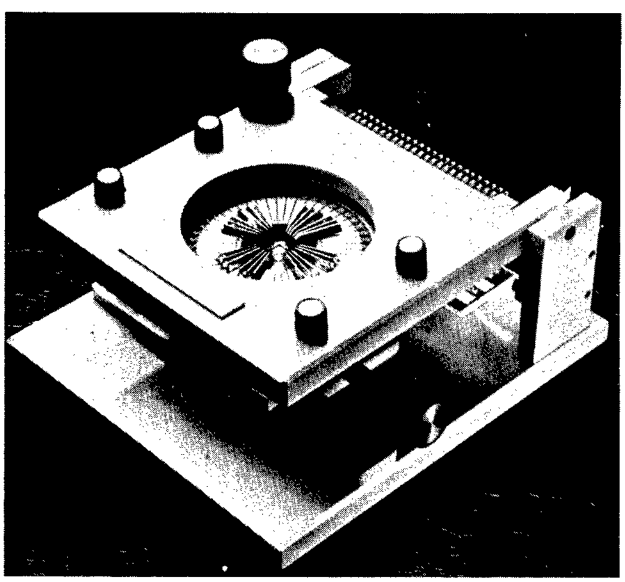


Figure 6

development version of the position computer circuit to be used in the Stinger Post weapon system.

The main function of this circuit is to convert digitally encoded target data into position information. Data calculations performed by the microprocessor discriminates a real target from false targets. The circuit generates a precession signal that keeps the gyro optics pointed in the direction of the target. This circuit is constructed on a ceramic substrate 3.6 square inches in area which has six conductor layers, five double-printed dielectric layers, and five via fill layers. There are 670 interconnection vias between conductor lines. The resulting multilayer substrate is populated with 98 electronic parts, including thirty-one integrated circuits. These integrated circuits range in complexity from simple inverters to a microprocessor, and include operational amplifiers, logic cell arrays, and ROM and RAM chips. In addition to the active components, the circuit contains 40 chip resistors, 14 capacitors, and 12 diodes. The complete hybrid circuit is shown in Figure 9.

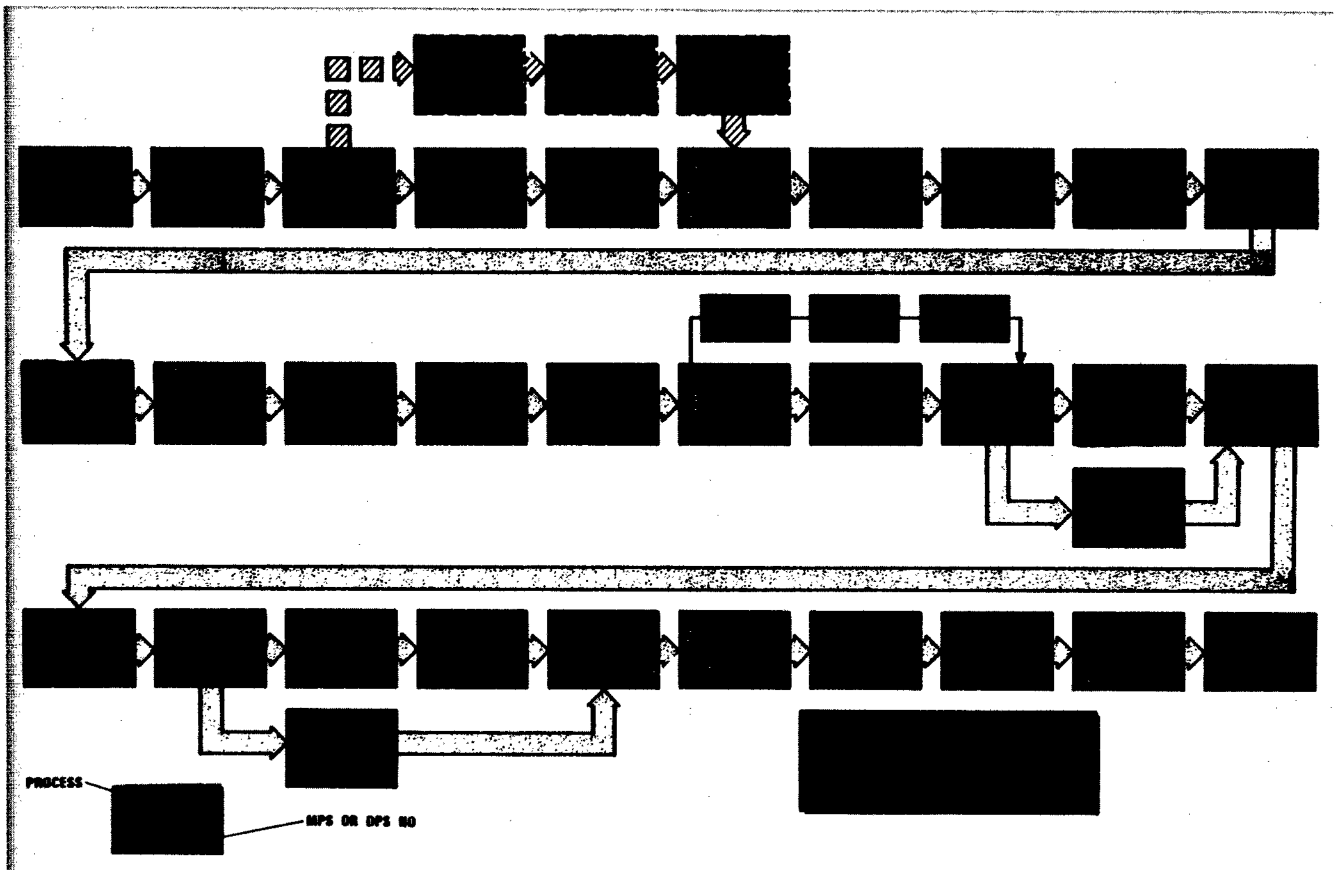


Figure 7

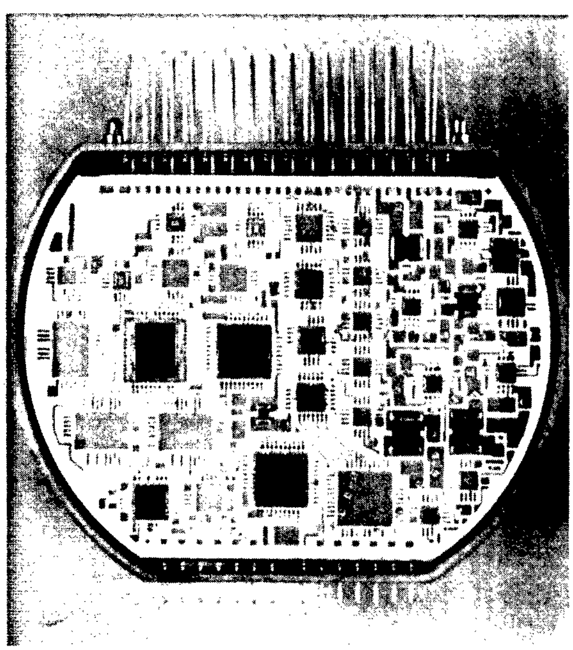


Figure 8

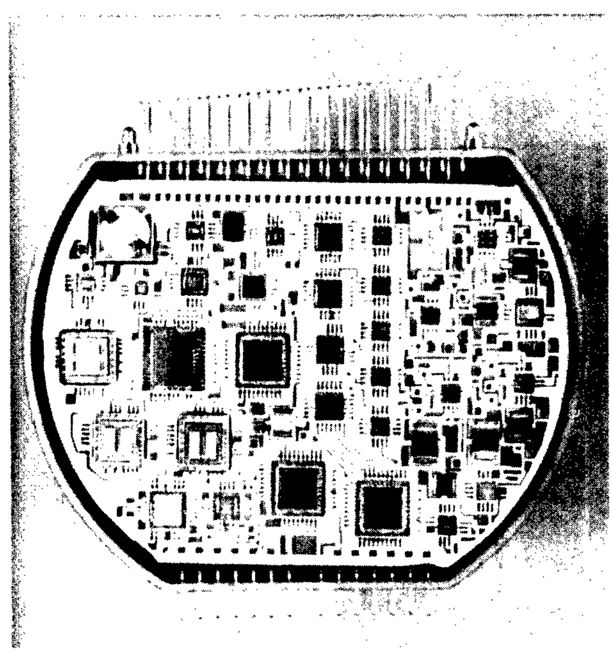


Figure 9

Multiple Benefits Realized

Ultrasonics Assists Tough Material Machining

BRUCE S. PARK is an Industrial Engineer in the Production Technology Branch, Directorate of Procurement and Production, U.S. Army Aviation Systems Command (AVSCOM). He holds a B.S. of Science in Civil Engineering from the University of North Carolina-Charlotte, and he graduated from the DARCOM Intern Training Center. During his six years at AVSCOM, he has performed a wide variety of engineering duties, including service on "should cost" teams, as Conference Coordinator of the AVSCOM Manufacturing Technology Conference III, as a member of the Nondestructive Testing Subcommittee of the Manufacturing Technology Advisory Group (MTAG), and activity as Project Engineer in the AVSCOM manufacturing technology program.

Photograph
Unavailable

Editor's Note: Work on this project was performed at Sonobond under the guidance of Janet Devine, Vice President of R&D, and Philip C. Krause, Vice President of Marketing. Attention is called to the excellent references and documentation in their report, which is available from the U. S. Army Aviation Systems Command technical representative (see Note opposite). Unusual abstracts from foreign sources are presented in the Final Report, Project 7156.

Ultrasonics has established itself in still another manufacturing operation following completion of a machinability MM&T project by Sonobond Corporation for the U.S. Army Aviation Systems Command. By providing ultrasonic activation of cutting tools during the machining of unusually difficult-to-machine materials, AVSCOM has increased material removal rates of these tough to shape materials by as much as 700 percent.

A tool post for ultrasonic activation of cutting tools on a turret lathe was designed, fabricated, and given preliminary evaluation on a LeBlond engine lathe, turning difficult-to-machine wrought metal alloys including ESR 4340 steel, 4340 steel, 9310 steel, 17-4 PH steel, several titanium alloys, and Refractaloy 26.

With the ultrasonic assist, metal removal rates were increased by factors up to 730 percent, tool wear and tool breakage were reduced, and tool chatter was eliminated. Ultrasonically cut chips had a larger curl radius indicating lessened strain, lower hardness, and less heat discoloration than conventionally cut chips. It was recommended that the ultrasonic tool post be refined and installed on a turret lathe for evaluation in a production environment.

Project Conclusions Reached

(1) Ultrasonic activation of cutting tools greatly facilitated the lathe turning of wrought metal alloys that are ordinarily difficult to machine, including ESR 4340 steel, 9310 steel, 4340 steel, 17-4 PH steel, several titanium alloys and Refractaloy 26.

(2) Rates of material removal for these alloys were increased by factors ranging from about 175 percent to more than 700 percent with ultrasonic assist.

(3) Both cutting speed and depth of cut were substantially increased over recommended standard cutting parameters.

(4) Tool wear, which is particularly severe in conventional cutting of such materials as ESR 4340 steel and Refractaloy 26, was significantly reduced with ultrasonic activation.

NOTE: This manufacturing technology project that was conducted by Sonobond Corporation was funded by the U.S. Army Aviation Systems Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The AVSCOM Point of Contact for more information is Bruce Park, (314) 263-3079.

(5) Tool breakage occurred less frequently with the ultrasonic assist, indicating reduced tool loading.

(6) Ultrasonically cut chips showed a larger curl radius and a lower hardness, indicating lower chip strain as a consequence of lower tool/chip friction.

(7) Chips from ultrasonic cutting showed less discoloration than conventionally cut chips, suggesting reduced heating effects.

(8) Tool chatter, which frequently occurred with heavy non-ultrasonic cuts, were instantaneously eliminated when the ultrasonic system was activated.

(9) No consistent effect of ultrasonic activation on surface roughness was apparent under the conditions investigated.

(10) The turret-type ultrasonic tool post is practicable, with interface modifications, for installation on a turret lathe.

Ultrasonic Power Increased

The program was undertaken to evaluate the technological and economic benefits achievable with ultrasonic energy application during lathe cutting of difficult-to-machine materials and to define requirements for ultrasonically processing such materials on a production basis.

Laboratory investigations during the past 20 years have demonstrated significant benefits with ultrasonic machining in terms of increased rates of material removal, decreased cutting forces, reduced tool wear, elimination of tool chatter, and altered surface finish. Most of this work involved the more readily machinable materials such as aluminum, carbon steel, austenitic stainless steel, and the like. Low-power (up to 600 watts) prototype ultrasonic systems were developed and successfully used for such applications.

The current work has extended the technology to materials that present machinability problems, particularly those used in the fabrication of Army aircraft such as the YAH-64. It involved the development of a high-power (4000 watts) ultrasonic machining system for installation on a turret lathe and preliminary evaluation with several high-strength materials designated by the Army.

Selected Materials Present Problems

Many aircraft parts made of metal alloys are difficult to machine by conventional methods. Materials such as 6Al-4V titanium alloy, hardened 17-4 PH stainless steel, and hardened 4340 and 9130 steel alloys have valuable properties such as high strength, high hardness, and good fatigue resistance, but high cutting forces are usually required and material removal rates are low. Turning operations for these materials are slow and costly. In addition, such materials tend to stick to the cutting tools and edge buildup on the tool frequently produces an undesirable surface finish.

Typical problems are encountered, for example, in the machining of large helicopter rotor head parts such as the following:

- With parts made of 6Al-4V titanium alloy, the turning speed must be slow enough so that a tool required to maintain satisfactory surface finish will not need to be changed during the final continuous cut.

- Thread milling at slow removal rates is required for external thread cutting of hardened 4130 and 4340 steel alloys. Poor surface finish is obtained with the more rapid lathe cutting of such threads.

- In straight OD turning, hardened 4130 steel requires low machining rates to avoid tearing of the surface.

Unusually difficult problems are encountered in the machining of the electroslag refined steels such as ESR 4340, which is used in drive control, flight control, and hydraulic systems. Because of the necessity for grinding to final surface finish, the turning costs may be tripled or quadrupled over the costs for the more common steel alloys. The fixturing must be more rigid because of the toughness of the material, and the turning feeds and speeds are slower. A typical material removal rate is 0.005 inch per pass to obtain the desired surface finish. Tool wear is rapid and tool breakage is frequent, and extreme care is required to prevent overheating of the material.

Such materials and operations are prime candidates for improvement, and ultrasonically assisted turning offers one avenue for such improvement.

Ultrasonic Machining Characteristics

The effectiveness of ultrasonic energy applied during lathe turning has been demonstrated in a number of investigations carried out in the United States and elsewhere.

One of the prime effects is a significant increase in material removal rate, as illustrated in Figure 1 for 2024-T3 aluminum alloy and in Figure 2 for 1018 carbon steel. These show a consistent pattern of increased cutting rate (up to fourfold) as the ultrasonic power level is increased without increasing the cutting torque.

Figure 3 shows the reduction in forces on the cutting tool with ultrasonic activation for these same materials over a range of material removal rates. Again the force reduction becomes greater as the ultrasonic power is increased. With such reduced forces, extended tool life can be anticipated.

The surface finishes obtained with ultrasonic and non-ultrasonic turning are shown in Figures 4 and 5. On the aluminum, the ultrasonic turned sections are characterized by a matte surface, while those non-ultrasonically turned are superficially shiny. In the high-magnification photographs, there appears to be less gouging and tearing of the surface with the ultrasonic assist. The minute striations of uniform regularity reflect the ultrasonic vibration cycles. Their spacing depends on the vibratory frequency in relation to the cutting speed.

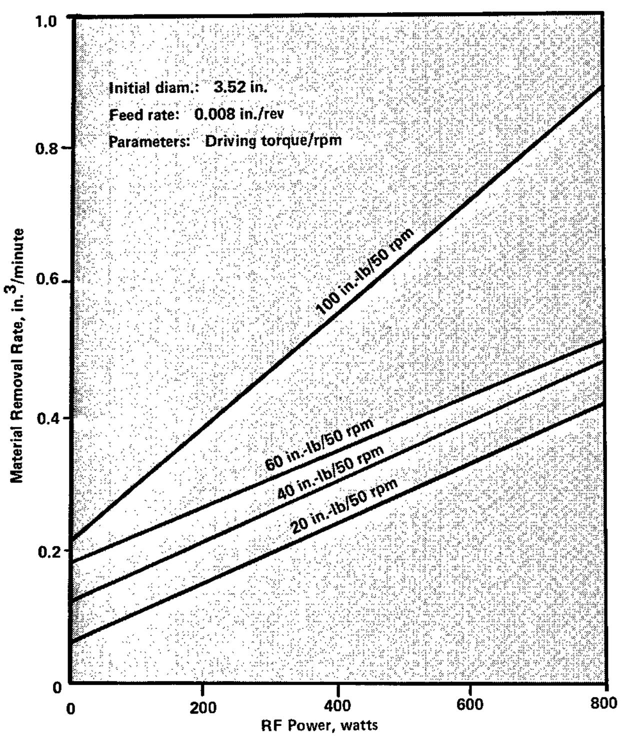


Figure 1

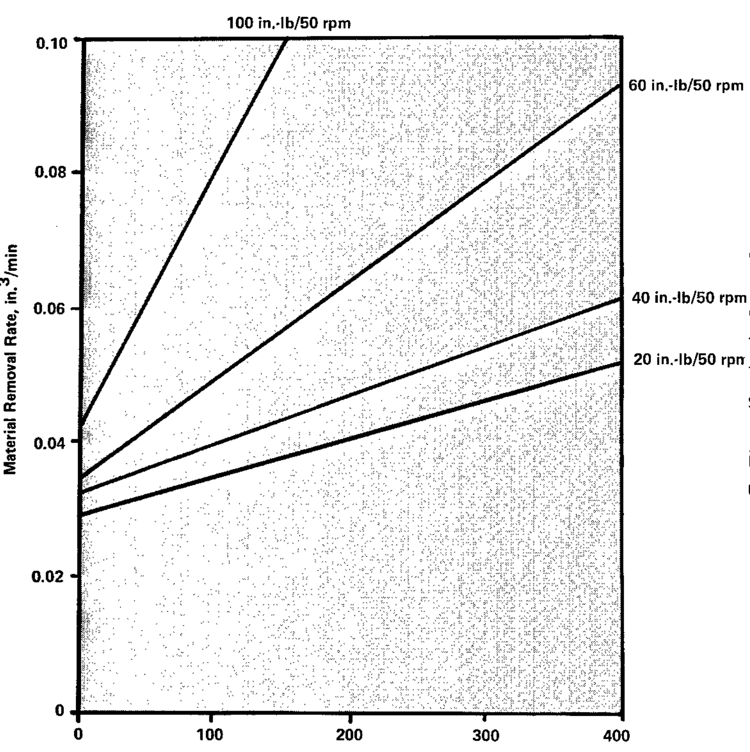


Figure 2

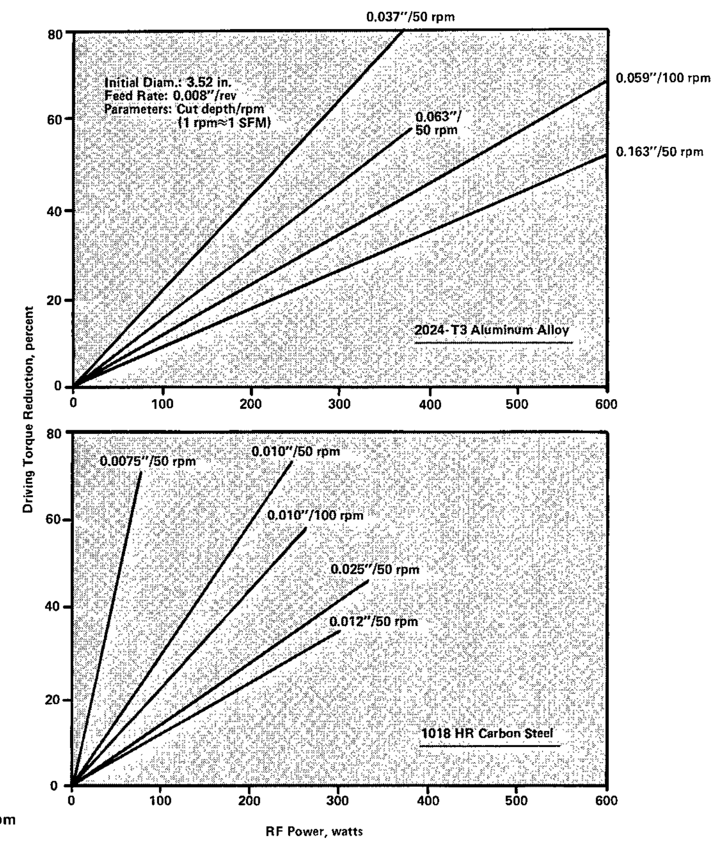


Figure 3

The striation effect is even more pronounced on the 1018 carbon steel (Figure 5). The non-ultrasonically turned section shows considerable gouging and tearing of the material.

Etched cross sections of the turned material are shown in Figure 6. Again the irregular gouging of the surface with conventional turning is apparent. By comparison, the ultrasonically turned surface is relatively smooth and there is little or no evidence of subsurface workhardening.

Visual and microscopic examination of chips obtained during machining of these materials (Figure 7) revealed, for the non-ultrasonically cut chips:

- A tight, small-radius curl
- A rough chip edge on the cut side, showing "tear-away" trails, indicating non-smooth cutting
- A generally shiny outer surface with evidence of burnishing, resulting either from the mode of cutting and tearing from the surface or from drag on the tool surface
- Erratic lateral flow and torn surfaces.

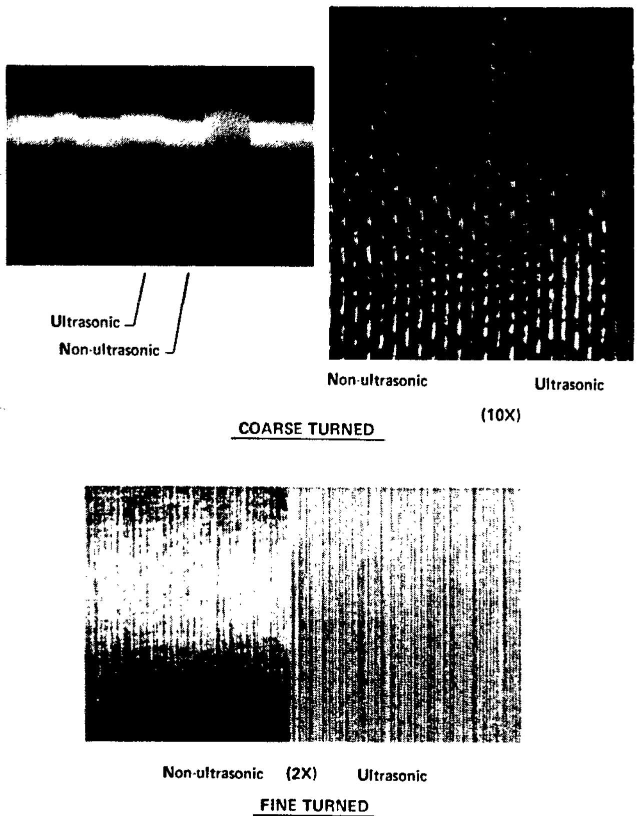


Figure 4

On the other hand, the ultrasonically cut chips were characterized by:

- A significantly greater radius for the curl
- A chip edge that was generally smooth, with evidence of a continuous cut and no indication of "tear-away"
- Outer curl surfaces of a matte finish, indicating relatively clean cutting and minimal drag along the upper surface of the tool
- Uniform lateral flow; both chip thickness and width were less than for non-ultrasonic chips.

A further observation during machining of these materials was the elimination of chatter. Under conditions that produced chatter with conventional machining, the chatter immediately ceased with ultrasonic activation and was initiated again when the ultrasonics was turned off.

Pursuant to these demonstrated benefits, prototype ultrasonic tool posts for both external and internal turning were designed and fabricated. These systems were effectively used in a production environment and confirmed the previously noted effects. The results obtained offered persuasive evidence of potential significant cost savings.

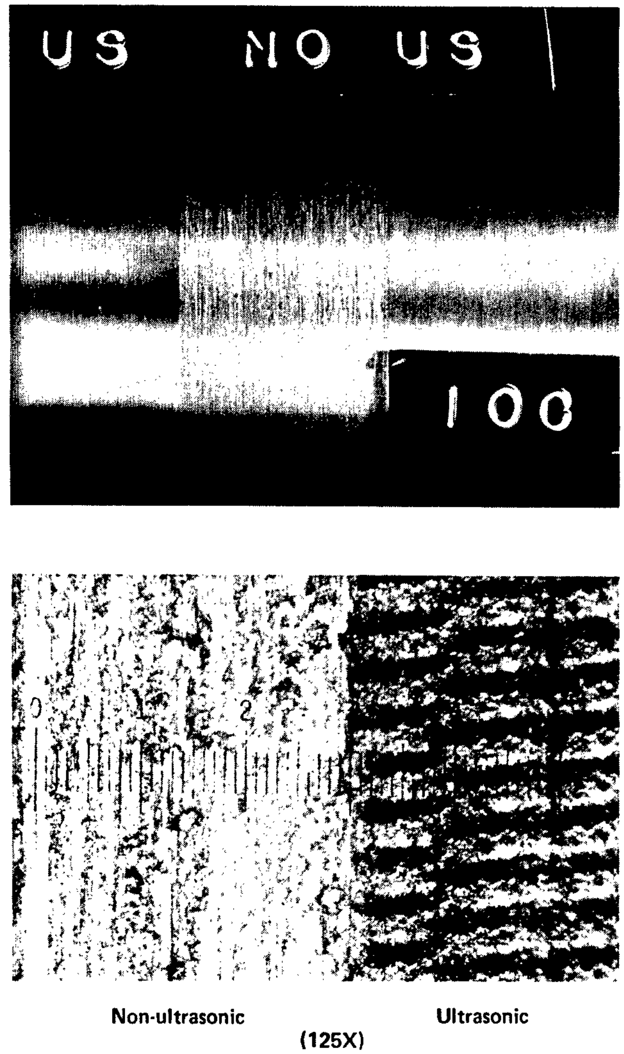
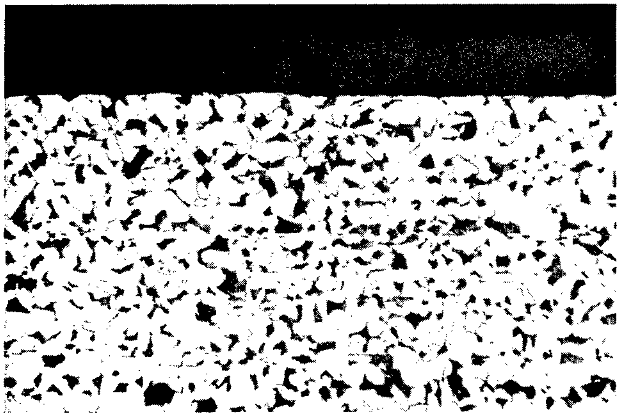


Figure 5

Ultrasonic Cutting Theory

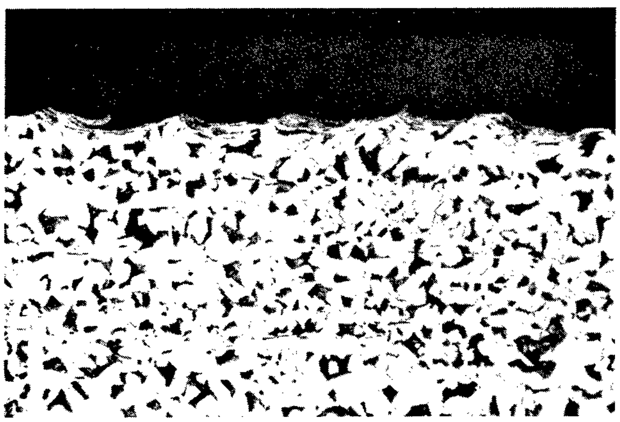
It has been postulated that two major processes occur during metal cutting: (1) plastic deformation along the shear plane immediately ahead of the tool and (2) friction between the tool and the workpiece. Investigators have estimated that about three-fourths of the total energy in ordinary machining is associated with shear, while one-fourth is consumed in friction. Both friction and shear create heat, raising the temperature of the workpiece, tool, chip and lubricant.

Ultrasonic application has been demonstrated both to facilitate plastic deformation and to reduce friction. Because of these effects, metal is formed more readily under ultrasonic influence by such processes as extrusion, tube and wire drawing, rolling, draw ironing, and the like, wherein reduced forces and increas-



Ultrasonic

(100X)



Non-ultrasonic

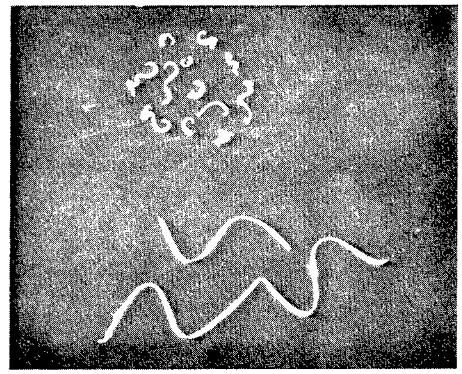
Figure 6

ed processing rates are characteristically obtained. These same effects are applicable in ultrasonic machining.

Numerous investigations have shown that the yield point of a metal can be significantly reduced under ultrasonic influence. Apparently, the high-frequency vibration lowers the forces required to move dislocations within the crystalline structure and to create new dislocations, so that the metal flows more readily.

In the machining process, this transient softening of the material relieves the workhardening that conventionally occurs in the area immediately ahead of the tool, so that stress distortion, fracture, and surface tearing are minimized.

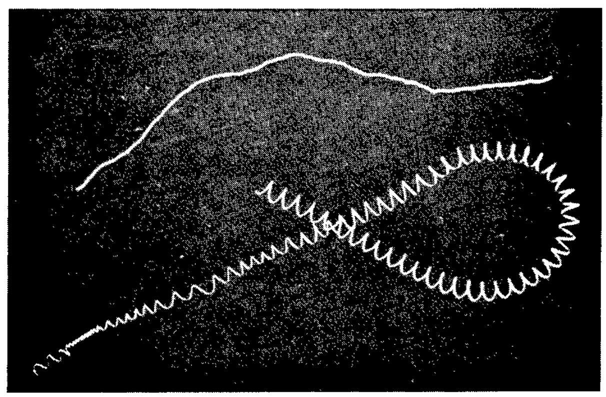
The reduced friction under ultrasonic influence is typified by greater ease in assembling components that are ordinarily difficult to assemble, as in press or interference fitting and in tightening or loosening threaded fasteners in wrenching operations. Studies made on surface layers of metals subjected to oscillating sliding friction have shown substantially less surface hardening than is obtained by unidirectional sliding. Apparently, the reciprocating action relieves a substantial amount of the distortional stress.



Non-ultrason

Ultrasonic

2024-T6 Aluminum Alloy



Non-ultraso

Ultrasonic

Figure 7 **1018 Carbon Steel**

In machining, this reduced friction can thus lead to reduced workhardening of the metal surface and reduced heat buildup in the material, leading to increased cutting rates.

Ultrasonic Lathe Cutting Systems

In any ultrasonic system that performs useful work, the flow of energy occurs as follows:

- Electrical power from a standard power line is delivered to a frequency converter which converts the 50/60 hertz power to the desired high operating frequency of the ultrasonic system.
- This high-frequency electrical power is applied to the ultrasonic transducer, which converts it to high-frequency vibratory power at the same frequency.
- The mechanical vibration is transmitted through a coupling system to the tool and thence into the material being processed.

Extensive theoretical and empirical studies have established basic design requirements for systems that will transmit the vibratory energy efficiently with minimum energy losses. Fre-

quency tuning and impedance matching throughout the system are essential.

Although there is a commonality of ultrasonic systems for various uses, each application demands consideration of the specifics for that particular process. The special considerations for ultrasonic machining include:

- Operating frequency of the system
- Mode and direction of tool excitation
- Tool and tool holder design
- Ultrasonic power level.

The effect of frequency per se is not significant in the range between about 5 kilohertz and 100 kilohertz, but practical considerations bracket a narrower range. The frequency should obviously be above the audible range, i.e., about 15 kilohertz or higher. The higher frequencies are power limited because of the smaller displacement amplitudes achievable. Frequency also dictates the physical dimensions of the transducer-coupling system required; the higher the frequency, the smaller the system. The practical range for machining is from about 15 to 30 kilohertz.

Investigations have established that the most effective vibratory mode in turning operations is in the direction of the cut, i.e., tangential to the rotating workpiece. Several have been evolved. A typical design is shown schematically in Figure 8. Figure 9 shows such a system mounted on a conventional engine lathe. In both cases, the tool post is clamped to the lathe cross slide and carriage unit.

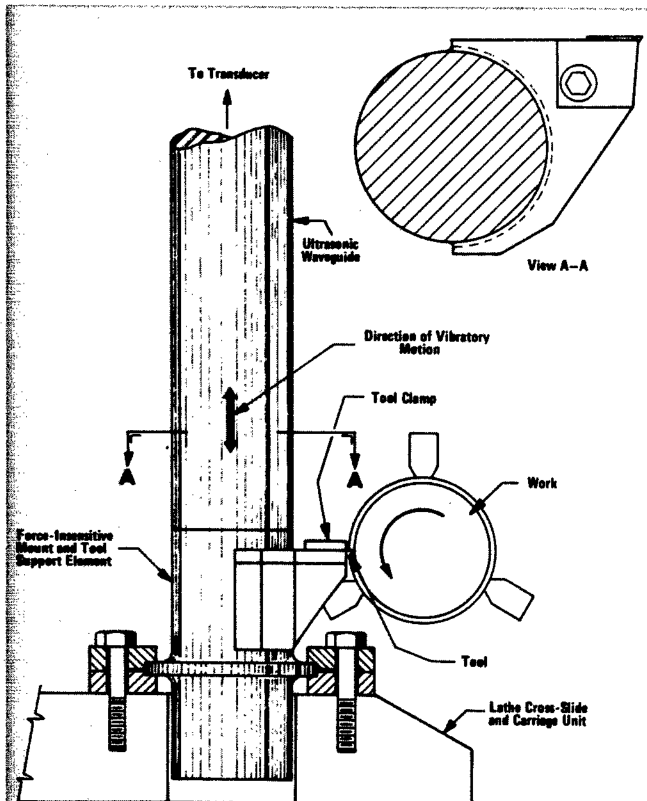


Figure 8

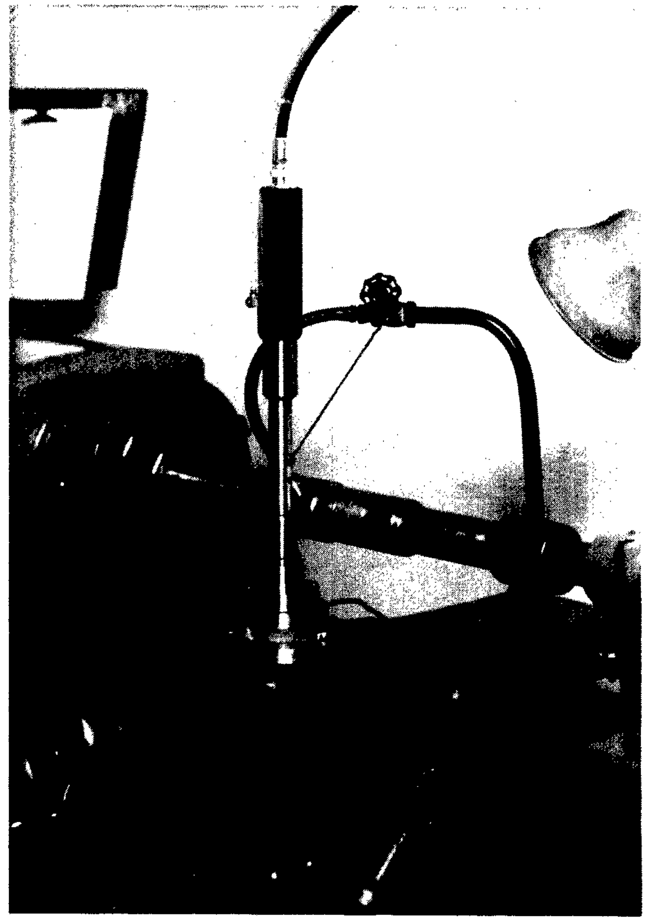


Figure 9

The tool post, tool holder and tool must fulfill acoustic requirements since they are integral parts of the ultrasonic transmission system. These components must be sufficiently rigid to preclude unacceptable tool deflection. The tool holder, in particular, should not constitute a large mass on the system, since massive tools reduce the vibratory amplitude that can be produced at the tool. All tool posts incorporate force-insensitive mounts which ensure negligible frequency shift and negligible energy loss to the support structure under the variable static loads associated with machining.

The power rating of an ultrasonic system is usually stated in terms of high-frequency (RF) electrical power delivered from the frequency converter to the transducer, because this value is readily measurable. It is not necessarily indicative of the acoustical power delivered to the work. Some power losses occur in the ultrasonic system itself. Piezoelectrical transducers of the type used are about 90 percent efficient in converting electrical to acoustical energy. Some additional energy losses may occur at the interfaces between transducer and coupler and between the coupler and the tool, but with a properly designed acoustic system, these losses are small.

The primary consideration is transmitting acoustic energy effectively from the tool into the work. This involves matching

the acoustic terminal impedance of the ultrasonic system to the impedance of the work. If precise matching is obtained, essentially all of the applied ultrasonic power is transmitted into the work locale. A large difference in these impedance values gives rise to reflections of power at the terminus of the ultrasonic system and limits the power that can be delivered.

The impedance of an ultrasonic system can be determined by a technique involving the use of small piezoelectric type strain gages attached one-quarter wave apart on a uniform section of an ultrasonic wave guide (or coupler). The output of these devices, after appropriate amplification and oscillographic display, yields an elliptical pattern whose area is proportional to the power transmitted through the wave guide. Furthermore, the ratio of the magnitudes of major to minor axes of the ellipse represents the standing wave ratio (SWR). Ideally, this ratio should be 1.0; higher values reflect inefficiencies in ultrasonic energy delivery.

An extension of this technique permits measurement of impedance matching into the work and provides a basis for cutting tool design. With one type of tool, for example, it was found that the extent of tool overhang significantly influenced power delivery. Other tool parameters can be evaluated in a similar manner.

Program Initiated

The first task of this ultrasonic machining program involved the design, fabrication, test and evaluation of an ultrasonic system for excitation of an existing production single-point tool turret lathe and installation of this equipment at the facility of an aerospace contractor designated by the Army. The company selected was Hughes Helicopters, Culver City, CA.

Hughes Helicopters, on the basis of their experience in the fabrication of aircraft materials, provided test bars of several materials selected on the basis of machinability problems. Hughes also provided the necessary cutting tools and tool holders and supplied consultative services throughout this initial phase.

Sonobond designed, fabricated and tested the required ultrasonic array and conducted preliminary cutting trials on the selected materials. Evaluation was made of ultrasonic versus non-ultrasonic cuts, primarily in terms of rate of material removed and tool wear.

It was initially planned that the first task would be concluded with shipment of the ultrasonic system to Hughes Helicopters and installation on a turret lathe at that facility. However, the preliminary efforts indicated the advisability of modifying the ultrasonic system for more effective operation in a production environment. Shipment of the equipment was therefore delayed pending completion of such modifications.

System Designed, Assembled

The first objective of the machining program was to design and assemble an ultrasonic lathe cutting system which consisted of a tool post capable of performing single-point metal cutting operations on an existing turret lathe; and a frequency converter of sufficient capacity to supply the required high-frequency electrical energy to the ultrasonic tool post. Appropriate interfacing of the tool post with the lathe to provide maximum efficiency of energy delivery to the work was an important part of this activity.

The ultrasonic system was projected for installation on an existing lathe at the Hughes Helicopters' facility. The selected lathe was a 30 horsepower saddle type lathe with the indexing handle located on the side of the saddle and the mechanism for 90 degree rotation below the cross slide.

A lathe of this type was not available at Sonobond, and initial evaluation was carried out on an existing 7 horsepower engine and diemaker lathe. Integration of the ultrasonic system with both lathes presented no major problems.

An effective ultrasonic tool post for a turret type installation basically consisted of an ultrasonic transducer to generate the high-frequency vibration and an acoustic coupling system to transmit the vibratory energy to the tool holder and tool insert.

Initially, consideration was given to the operating frequency and required power rating of the ultrasonic system. The frequency selected was 15 kilohertz, which would provide maximum amplitude of vibration within an acceptable noise level.

Past experience had shown that the ultrasonic power level, to have an appreciable effect in ultrasonic cutting, should be about 15 to 20 percent of the mechanical power level required to perform the task. Based on this empirical ratio, the ultrasonic system power capacity for a 30 horsepower lathe should be within the range of 3375 to 4500 watts. For the lathe of 7 horsepower capacity, the required ultrasonic power would be within the range of about 800 to 1050 watts.

Accordingly, it was decided to design the system for operation at 15 kilohertz and 4000 watts. An ultrasonic transducer and matching frequency converter at these ratings are standardly used in Sonobond's largest commercial ultrasonic spot welder, so these component designs were immediately available.

The standard 4000-watt piezoelectric transducer (Figure 10) consisted of disks of lead zirconate titanate polarized in the thickness mode, incorporated in a rugged assembly of the tension shell type with a bias compressive stress on the ceramic disks to preclude failure under dynamic stress. Cooling channels permitted cooling air flow through the assemblies to prevent overheating and depolarization of the transducer elements.

A coupler or wave guide to operate at the 15 kilohertz design frequency was designed and fabricated. This component incorporated a force-insensitive mount to isolate the system from the lathe bed.

Figure 11 shows schematically the final design of the ultrasonic tool post that was mounted on the 7 horsepower lathe.

The frequency converter was a hybrid-junction transistorized solid-state device consisting of an amplifier and oscillators to supply the high-frequency electrical power to the transducer. The output frequency of the system could be fine tuned to precisely match the operating frequency of the transducer coupling system.

For mounting of the ultrasonic system on the turret lathe, an unfinished forging of standard turret was obtained. The upper

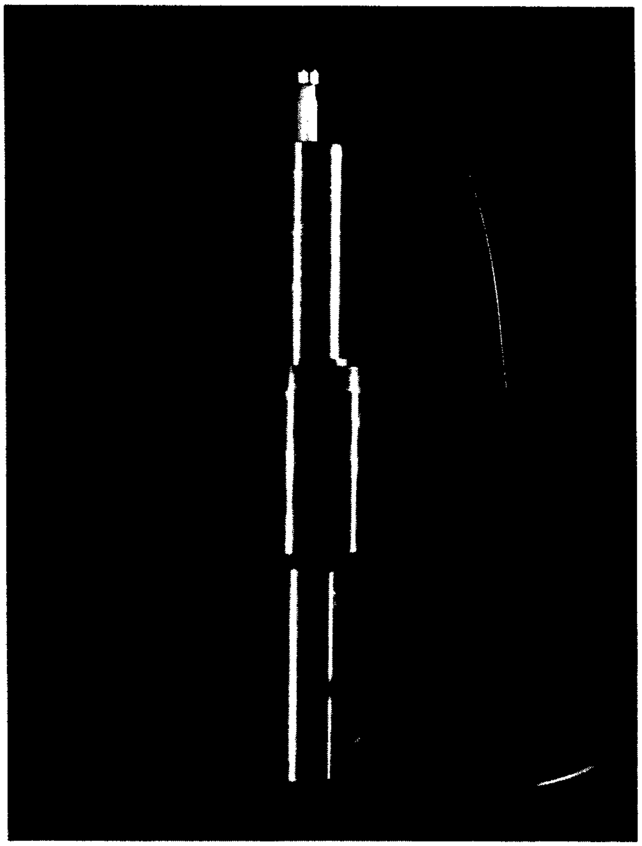


Figure 10

part of this forging was removed and the lower part was machined to provide a proper fit.

Tool Holders and Inserts

Representative tool holders and tool inserts were selected and supplied by Hughes Helicopters. Tool inserts were of a type and material frequently utilized in machining problem materials—tungsten carbide base with 10% cobalt.

Materials Selected Jointly

The basic materials for evaluation of ultrasonic cutting were selected by joint consultation involving the Army, Hughes Helicopters, and Sonobond Corporation. These included:

- 9310 Low-carbon steel
- 4340 Medium-carbon steel
- 17-4 PH Stainless stell
- ESR 4340 Electroslag refined steel
- 6Al-4V Titanium alloy.

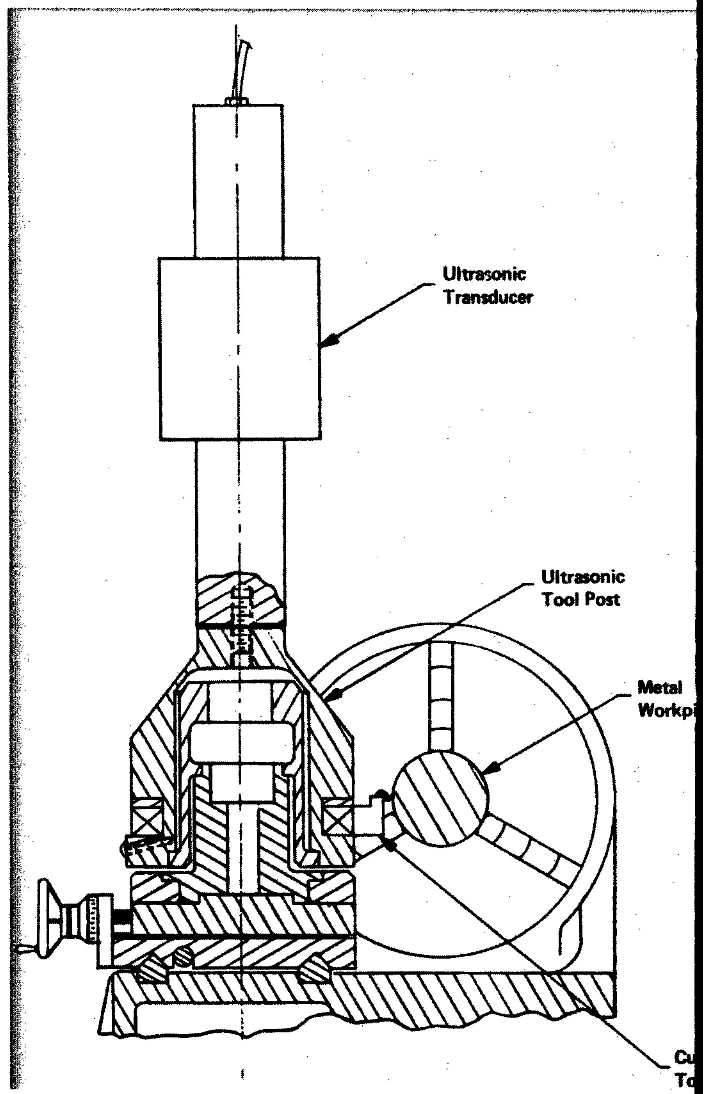


Figure 11

These materials were recognized to present machining problems, especially in terms of slow material removal rate, rapid tool wear, or difficulties in attaining acceptable surface finish.

Bars of these materials, usually 3 inches in diameter by 15 inches long, were supplied by Hughes Helicopters each in the heat-treat condition characteristic of the state in which it is used in fabrication of aircraft components. For example, Ti-6Al-4V alloy was supplied in the annealed condition because it is generally used in this state. The steel alloys were all heat treated to the desired hardness.

Additional materials were supplied by other companies interested in ultrasonic machining and it was agreed that the data should be reported herein. Pratt & Whitney Aircraft Group supplied some bars of titanium/aluminum alloys—Ti-Al and Ti-3Al—which generally are not easily machinable. Westinghouse Electric Company, Turbine Components Plant, provided bars of Refractaloy 26, a material used for turbine shafts. This material is capable of being machined, but cutting tool wear is excessive.

Data Recorded, Compared

Bars of the material to be machined were turned on the lathe under selected cutting conditions both with and without ultrasonic application. Baseline data for conventional (non-ultrasonic) cutting of some of these materials were obtained for 9310 steel, 4340 steel, 17-4 PH steel and 6Al-4V titanium alloy. For the remaining materials, cutting conditions were selected empirically or at the recommendation of the material suppliers.

Data were recorded for the cutting speed in surface feet per minute (SFM), calculated from rod diameter and rotational speed in revolutions per minute (RPM), feed rate in inches per revolution (ipr) and depth of cut in inches. These data were used to calculate the rate of material removal in cubic inches per minute. Ultrasonic power level was also recorded in all runs. For evaluation of surface finish, the cut surfaces were scanned with a Brush Surfindicator.

General Observations

The results of these evaluations of ultrasonic machining generally confirmed the results obtained earlier with more readily machinable materials. Non-ultrasonic cutting was frequently characterized by tool chatter, which was virtually eliminated with ultrasonic activation. This phenomenon was audibly apparent whenever ultrasonics was turned on or off during a particularly heavy cut.

The chips from non-ultrasonic cutting were sometimes blue or burnished: no such discoloration was apparent with the ultrasonically cut chips, indicating the absence of detrimental overheating of the tool and the work material.

Ultrasonics substantially accelerated the rate of material removal with these difficult-to-machine materials, and tool wear was reduced.

Breakage of the carbide tool insert occurred under certain cutting conditions, apparently because the capability of the 7 horsepower lathe was being exceeded. Such breakage usually occurred more readily with the non-ultrasonic than with the ultrasonic cutting. In some instances, the tool broke instantaneously when the ultrasonic system was turned off during a cut. This suggests that the tool loads were lower with ultrasonic activation.

Surface Finish Inconclusive

Controlled experiments were made with four materials to evaluate the ultrasonic effect on surface finish. Cuts were made at slow material removal rates characteristic of finish cuts. These experiments were carried out with and without lubricant/coolant, without ultrasonics and at ultrasonic power levels of 1000 and 2000 watts.

The data show no consistent pattern of an ultrasonic effect on surface finish. In some instances, the surface finish was smoother and in others it was rougher with ultrasonic application. There appeared to be a trend toward improved finish when the coolant was used at 1000 watts ultrasonic power, as if the vibratory energy aided in pumping the liquid into and out of the cut, but the ultrasonics did not always effect improvement.

Surface finish data obtained sporadically on rough machine cuts likewise showed inconsistencies that could not be explained. This effect requires further evaluation after equipment modification.

Material Removal Rates

One of the major demonstrated effects of the ultrasonic assist to machining was the substantially increased rates of material removal. It was possible to increase both the cutting speed and the depth of the cut.

9310 Steel. With this material, the rate of metal removal was increased from 14.04 cubic inches per minute, as recommended for conventional cutting, to 24.75 cubic inches per minute with ultrasonics, an improvement factor of 1.76. Although tool breakage occurred at some of the higher removal rates, this was attributed to limitations of the lathe and not the ultrasonic system.

4340 Steel. Good cuts on the 4340 steel were obtained at removal rates up to 15.47 cubic inches per minute, compared to a recommended rate of 7.56 cubic inches per minute. The improvement factor here was 2.05.

17-4 PH Stainless Steel. A substantially greater effect was obtained with this material. A low removal rate of 3.42 cubic inches per minute was recommended. Ultrasonics permitted cutting at rates up to 25.02 cubic inches per minute, an improvement factor of 7.32. Stalling of the lathe became a factor at the higher cutting rates.

ESR 4340 Steel. Baseline data for this material was not available. Accordingly, several cuts were made without ultrasonics. Very low removal rates were obtained—less than 1 cubic inch per minute—and these were limited by rapid tool wear. When the ultrasonics was turned on, the improved cutting was immediately apparent and good cuts were obtained at rates up to 4.12 cubic inches per minute.

6Al-4V Titanium Alloy. Recommended machine settings specified a material removal rate of 4.86 cubic inches per minute. With ultrasonics, rates up to 15.14 cubic inches per minute were possible, an improvement factor of 3.17.

Titanium/Aluminum Alloys. These alloys were reported to be very difficult to machine by conventioinal methods and were stated to be subject to severe tearing and surface damage. Good cuts were obtained ultrasonically at a rate of 1.21 cubic inches per minute.

Tool Wear

Some of the materials investigated, particularly ESR 4340 steel and Refractaloy 26, reportedly induce rapid tool wear and/or breakage in conventional machining. A few experiments were oriented to determining the ultrasonic effect on this phenomenon.

In almost every instance, ultrasonic application substantially increased tool life. With the Refractaloy, for example, under one set of conditions the tool broke after 2.5 inches of conventional cutting and after 10.5 inches of ultrasonic cutting. With the maximum removal rate used, 3.92 cubic inches per minute, the tool in conventiional cutting was worn 0.07 inch after 4.8 inches of

cutting, while that used in ultrasonic cutting was worn only 0.03 inch after 5.1 inches of cutting.

Even greater effect was obtained with ESR 4340. After 0.3 inch of conventional cutting, the tool burned and broke. In ultrasonic cutting, the tool showed only 0.014 inch of wear after a 16.5 inch cut.

Chip Characteristics

Comparison was made of the chips removed from the metal with ultrasonic and non-ultrasonic turning. Typical chips obtained under both conditions are shown in Figure 12. In all instances, the ultrasonic chips were characterized by a much larger curl radius, suggesting that less strain was induced in the chip as a result of ultrasonic activation.

A metallographic analysis of representative chips produced with and without ultrasonic assist was made by Professor Kenneth J. Trigger of the Department of Mechanical and Industrial Engineering, University of Illinois at Urbana-Champaign, IL.

Chip samples of 4340 steel were examined microscopically and measurements made on the free surface, of 4340 steel, i.e., the side opposite the tool-chip interface. The free surface of a continuous chip (not a so-called brittle chip as in cast iron) is typically a lamella-like array. The spacing of the lamella is dependent upon the shear behavior of the tool, the tool geometry, and, especially, the tool-chip friction at the interface. In this comparison, the only variable was the tool-chip formation.

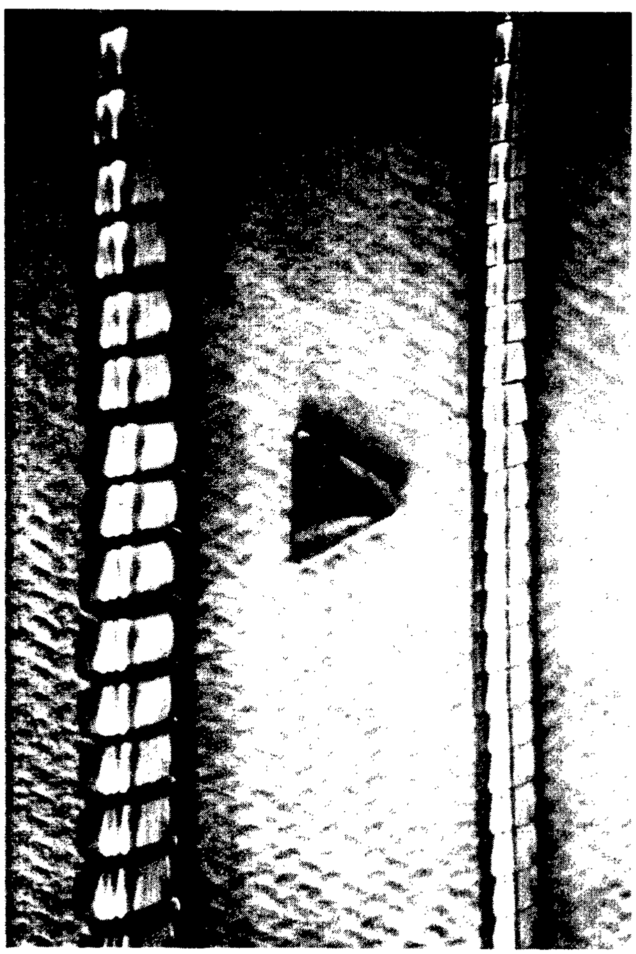


Figure 12 **Ultrasonic** **Non-ultrasonic**

The chips were examined with a low-power microscope equipped with a filar micrometer eyepiece, giving an overall magnification of approximately 20X, and the lamella spacings were measured. Five to eight measurements, each involving a minimum of 20 lamella, were made on representative samples for each test condition. In addition, the average chip thickness from the tool interface to the midpoint of the free surface was measured. The results were as follows:

- With Ultrasonic Assist
  Lamella spacing: 0.0067—0.0075 inch
  Average chip thickness: 0.012—0.013 inch
- Without Ultrasonic Assist
  Lamella spacing: 0.0085—0.0095 inch
  Average chip thickness: Approximately the same as above, but lamella plate projections were higher and less regular.

Chip samples were tested for microhardness with a 136-degree square base diamond pyramid indenter at 2 kilograms load. The higher chip body hardness in the non-ultrasonic chip is probably due to the higher chip strain as a consequence of high tool-chip friction.

Results Show Positive Benefits

These preliminary machining studies indicated positive and significant effects of the ultrasonic assist in terms of increased material removal rates and reduced tool wear. The equipment and experimentation satisfied the basic requirements of the contract. However, the work also indicated the need for further modification and refinement of the ultrasonic equipment for evaluation in a production environment, as outlined:

(1) The ultrasonic equipment should be modified and refined for evaluation on a turret lathe in a production environment; such modifications should consist of

(a) Redesign of the ultrasonic tool post to provide improved, positive tool retention

(b) Installation of a power interlocking system to provide automatic activation of ultrasonic power when the cutting load is initiated

(c) Development of feedback circuitry that will match the ultrasonic power delivery to the tool load in order to maximize impedance matching at the tool/work interface under varying machining conditions.

(2) It is recommended that a production turret lathe be equipped with the modified ultrasonic system for detailed evaluation of the effectiveness of ultrasonically assisted turning under production conditions.

Brief Status Reports

Project 3010. Millimeter-Wave Sources for 60, 94, and 140 GHz. Analysis of pilot production run of 14 lots of D-band, V-band, and W-band silicon impatts indicate an overall yield of 25 percent. Diode cost is reduced from $400 to $60. MMT modulator is unstable. TRW modulator will be used instead. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3011. Indium-Phosphide Gunn Devices. The two EPI layer process yield is 90 percent. Although process problems still exist, the INP gunn diodes are surpassing the requirements of the MMT at 56 and 94 GHz. The thinned integral heat sink is still problematic. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3023. Tubular Plasma Panel. An industry demonstration of the manufacturing facility was held. A no-cost extension of one year was granted to Norden. At that time, Norden will deliver a mifass panel for use in a display simulator. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3026. High Pressure Oxide IC Process. The revision of the furnace improved performance at low pressure/high temperature. At 1000 psi, convective heat loss prevented attainment of 750 C. Autoclave Engineers, Inc. will study requirements to complete. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3501. Third Generation Photocathode on Fiber-Optic Faceplate. ITT Roanoke is reevaluating processing procedures because of cosmetic discrepancies on 25mm 0.9 micron 3rd generation photocathodes on fiberoptic faceplates. Bonding problems were resolved. May go to metal organic vapor phase epitaxy growth. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3505. High Contrast CRT Phosphor Deposition and Sealing. Hughes has delivered confirmatory samples including one operable CRT and several multi-phosphor faceplates. Completion of fabrication facilities in compliance with OSHA standards has resulted in unanticipated expenditures. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 3505. High Contrast CRT Phosphor Deposition and Sealing—Phase II. Additional confirmatory CRTs are complete under Phase I. Descoping Phase I for confirmatory CRT samples is being discussed with procurement. Effort on Phase II is currently low level. For more information, contact Joseph Key, ERAD—COM, (201) 544-4258.

Project 5010. Bonded Grid Electron Gun. Boron nitride grid blocks from Union Carbide had wrong curvature radius. They made another lot. Experiments for attaching grid blocks to cathode are on-going. J.K. Lasers is experimenting with the required laser milling. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5019. Laser-Cut Substrates for Microwave Tubes. 15 S-band and 15 C-band anode circuits have been fabricated and successfully passed testing. Copper-tungsten ground plane thermal expansion problem was analyzed metallurgically and solved. Laser Services, Inc. uses well known CO2 laser cutting on BEO. Phase II objective is to incorporate the new anode circuit into CFA tubes. Confirmatory samples of 2 C-band CFA and 2 S-band CFA to be delivered. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5041. Millimeter Wave Mixers and Arrays. The contract has been descoped to delete the 140 GHz mixer because of unresolvable problems. Ten each of pilot run samples at 56 and 94 GHz will be delivered. This mixer design is generic and can be used in many missile seekers and communications sets. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5107. 94 GHz Pulsed Power Combiner. Work was redirected to a solid state amplifier for Milstar, a $500 million program. This low noise amplifier for satellite communications will be made using standard litho techniques rather than electron beam writing. Will automate impatt amp production. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5109. Precision Low-Cost Surface Acoustic Wave Delay Lines—UHF Application. TRW is fabricating 403 KHz and 506 MHz saw delay lines. Phase I engine samples were subjected to mechanical, environmental and electrical tests. Deficiencies will be corrected prior to submission of 2nd engine sample lot. Major end item is AN/TMQ-31. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 6350-2200. Automated Identification, Sizing, and Counting of Particulate Contamination. The technical work for this project has been completed. The technical report has been submitted. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 5071-80. Computer-Aided Test Planning. The CAT plan is dually operational as the central tool for producing USATTC detailed test plans. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-100. Automatic Particle Contamination Measure in Hydraulic Oil. After trying diesel fuel, lube oil, hydraulic fluid gives the most consistent results and will be used as the base oil for dilution of small samples of contaminant oil. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-57. General Purpose BIT Slice Microcomputer. The general purpose BIT-slice microcomputer interface is complete and resides in the Data General Eclipse SL250 minicomputer and Data General Eclipse SL130 minicomputer. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 7119. Non-Destructive Evaluation Technique for Composite Structures. Part II of the handbook on physiochemical characterization techniques was completed. Reviews of liquid chromatography, real time thermography, ultrasonic, and acoustic emission QC techniques, and of the QC of the AH-1 blade are in process. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7197. Fabrication of Integral Rotors by Joining. Machining of rotors for engine testing complete. Crack growth data generation for all CAP and HIP material to substantiate rotor life in accordance with inspection guidelines in progress. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7202. Application of Thermoplastics to Helicopter Secondary Structures. Final assembly of the prototype doors was completed. Results of structural tests demonstrated good structural properties. Implementation plans consist of flight testing of the CH-47 engine access door assembly pending safety-of-flight release. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7288. MMT Determination Optimal Curing Conditions. Prepreg E-glass and S-2 glass/epoxy formulations were autoclave cured to under, standard, and postcure conditions. Specimens from each condition are being tested mechanically and chemically (fourier transformation infrared spectroscopy). For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7298. High Temperature Vacuum Carburizing. Initial process development has been completed. Metallurgical examinations were performed on three test 9310 steel slugs. Carburization requirements were satisfactory, but microstructural property results dictated changes to the carburization process. Approximately 75 percent of the 9310 steel gear roller specimens have been tested. Metallurgical evaluation revealed unacceptable microstructural characteristics. New test samples at different heat treatment parameters have been prepared. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7322. Low-Cost Transpiration-Cooled Combustor Liner. Work continuing on schedule. 4000 amp pulse rectifier has been purchased by DDA. Various parameters which affect etching rates and quality of pattern are being evaluated to speed fabrication and reduce cost. Sheets placed in metal bag improved quality. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7340. Composite Main Rotor Blade. Work was conducted to resolve the HHI vibration problem. A resolution of the problem was not achieved before MT funding was expended. A draft final technical report has been prepared. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7371. Integrated Blade Inspection System (IBIS). Work continued on the XIM portion of IBIS. Acquisition and fabrication on some XIM hardware has been accomplished. Development of computational software continues; it is used in detecting and analyzing flaws. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7376. Automated Inspection and Precision Grinding of SB Gears. Final inspection process has been demonstrated. In-process inspection process development is under way. Originally specified computer hardware was insufficient and a larger unit is being procured. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 7382. Low-Cost Composite Main Rotor Blade for the UH-60A. Fabrication of the 5 short spar sections has been completed, and ballistic and process verification testing has been initiated. Contract is being modified to eliminate cocured blade process in favor of a precured spar concept.

Project 8190. Improved Cutter Life, T-700 Computer Blisk/Impeller Milling Operations. Statistically designed experiments have identified a potentially optimum combination of tool

material and geometry and feeds and speeds. Verification testing will be conducted. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 8192. Turbine Engine Productivity Improvement. Project is proceeding on schedule with no slippage anticipated. Operational sorting network system used for group classification. Metalmats system used for computer generation of routings and time standards. For more information, contact Gerald Gorline, AVRADCOM, (314) 263-2318.

Project 3054. Production Methods for Multi-Layer Folded Circuits. Hughes completed testing rigid-flex circuit board samples with positive results. Board fabrication now delayed due to eprom reprogramming. Goals are to automate rigid-flex board manufacture, select compatible materials, and create process specifications. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3057. High Stability Vibration Resistant Quartz Crystals. Frequency Electronics is building a pilot line for 5 MHz SC cut quartz crystals in ceramic flatpacks. Automatic X-ray, cut and grind angle correction, and parallel gap welding were developed. Bake and seal stage for 48 units was designed. Plating tested ok. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3068. Increase Producibility of Varactors and Pin Diodes. GaAs varactor chip design requirements have been finalized. Epitaxial dopant curve was developed. Silicon pin diode materials were ordered, process flow sheet was completed and the mesa etches are characterized. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3073. Tactical Graphics Display Panel. GTE Corp. experienced row shorting problems in fabricating 10 x 12.5 in. thin film electroluminescent display panels. Diagnostic tests are under way. Drive electronics almost complete and testing has begun. Pilot line producing 10 panels a day is goal. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3083. MM Wave Communications Front End Module (CFEM). A contract was awarded to establish a capability to build integrated mm wave front end transmit-receive modules. Will include transmitter source, bite test coupler, transmitter power attenuator, filter, mixer, source and preamp. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 9898. Ruggedized Tactical Fiber-Optic Cables. Pilot production of the military fiber-optic cables is currently ongoing. Contractual agreements on device specification have been made. A full 6-part military specification was jointly generated. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 1042. Production of Composite Radome Structures. The production rate of the roving saturation equipment was increased. Process plans and tooling designs were established. Tooling was fabricated. Funds will be reprogrammed to also award a contract for production proveout of single layer design. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1051. Replacement of Asbestos in Rocket Motor Insulations. Task 1 of the four contractor efforts to find replacement formulations for composite propellant grain inhibitors, smokeless insulators, and flexible rocket motor insulator were successful. The contracts for Task 2 for 3 of the 4 contractor efforts have been placed. The contract for the fourth effort is in process. Task 2 work consists of scaling up the processes for the candidate materials to full scale components. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1060. Electrical Test and Screening of Chips. Test system mechanical specification with rotating arm was prepared. Planned computer control architecture supports four functions: pattern recognition, host simulator, direct chip probe/testing controller and workstation controller. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1075. Electronics Computer-Aided Manufacturing (ECAM). Battelle developed a master plan defining the MT projects needed to realize a computer-aided manufacturing capability. Automation and CAD/CAM technologies were addressed. Descriptions of future manufacturing projects were developed and prioritized. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1086. Cobalt Replacement in Maraging Steel Rocket Motor Components. This Phase 2 effort is essentially complete. A final report covering this phase has been drafted and will be distributed. Phase 3 effort is just getting started. Milestone chart is being prepared pending contract finalization. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1108. RF and Laser Hardening of Missile Domes. Battelle sputtered an indium tin oxide coating onto 60 domes to evaluate its laser energy

shielding capability. Also, a fine copper and nickel grid was blated onto the inside of domes to give them radio energy shielding. A demo was held for industry. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1109. Robotized Wire Harness Assembly System. The subsystem specification documentation was officially released into the Boeing Documentation System. This document includes both hardware requirements specification and software design specification hardware design equipment specification. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1121. Missile Manufacturing Productivity Improvement Program. A scope of work was prepared and meetings held with Navy and Air Force. A contract will be negotiated with Martin Marietta to analyze their subcontractors manufacturing planning to find productivity and business system improvements. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1126. Wound Elastomer Insulator Process. Case bond aging tests continued. Adhesion tests of the 4 wound elastomeric insulator candidate formulas to the molding formula for premolds were conducted. Design verification studies continued. Hercules received the authority to proceed with Task II (FY 83 funding) on May 6, 1983. Hercules recommended that integral thrust reversal adapters are feasible with the wound elastomeric insulator program. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project3411. Non-Planar Printed Circuit Boards. Assembly of 5 antennas is in progress by Multimetrics Inc. The trimming fixture required for the balon assembly has been utilized to fabricate a series of test spirals. These will be tested for gain uniformity, pattern shape and axial ratio. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5005. Computer-Aided Design for Cold Forged Gears (Phase I). The data section of the computer program that will handle gear geometries. The drawing routines were modified to accommodate helical gear geometry. The appendices dealing with various analysis have been completed. (Phase II): Two gears (one spur and one helical) have been chosen for use in the forging trials. The gear drawings are being evaluated and will be sent to TACOM for approval. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5082. Flexible Machining System, Pilot Line for TCV Components. Phase I is technically complete. A FMS manual with supporting software has been developed. Phase II also is technically complete. Contract consulting support was provided to four installations to determine the feasibility and configuration of FMS. The last phase of a five phase program will provide support to DOD contractors who are planning to install and/or optimize FMS. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5083. Upscaling of Advanced Powdered Metallurgy Processes-PH 3. Seven No. 6 AGT 1500 engine accessory gears have been forged. Complete die fill has been obtained and quality appears excellent. TRW will forge a gear for the M2/M3 instead of another ACT 1500 engine accessory gear. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5090. Improved and Cost Effective Machining Technology (Phase IV). Data collection nearly complete. Results submitted on the HZB301 experimental armor. (Phase V): contractor has begun visits to vehicle/component contractors and is selecting possible candidate components for non-traditional machining processes. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5091. Heavy Aluminum Plate Fabrication (Phase I). Aluminum armor plates and welding electrodes ordered and received. Holding fixtures and weld joints designed. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6011. Springs From Fiber/ Plastic Composites. Lab testing has been conducted to verify the adequacy of the design for the rear leaf spring set. A high stress rate was used to minimize the test duration. Ten sets of springs have been made. Front spring assembly was redesigned for composite materials and manufacturing processes. Dies were designed and fabricated. All required material was procured. Fabrication was deferred until testing was completed for the rear leaf spring. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6028. Production Quality Control by Automated Inspection Equipment. A new TDP for on-line evaluation of the AIDS was prepared and the contract was awarded. Control software for the 6V53 engine was generated by the contractor. Hardware evaluation has begun. The ABS compression test will be evaluated in the latter part of '83. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6038. High Deposition Welding. Flux core welding, H-plates welded. Submerged arc welding parameters established. Narrow gap welding equipment being adjusted. Plasma M16 equipment being selected. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6054. Advanced Metrology Systems Integration. The state-of-the-art metrology system survey was completed. The needs analysis and SOA report are in process. Function models of current factory practice as revealed by industry surveys have been reviewed and approved. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6089. Abrams Tank Plant—Technical Modification Program. A preliminary scope of work has been developed for Phase I on the IPI. This IPI will encompass four plants, Detroit ATP, Lima ATP, Scranton and Sterling Heights. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6098. Production of Special Armor Steel. Steel produced meets the established requirements of texture and hardness. Preparations have been made to roll half inch thick and less. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6099. Manufacturing Methods for Specialized Armor Materials. AMMRC, ARRADCOM, and PMB have initiated activity in the areas of materials, processes and facilities toward realizing the program objective. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 7580. Pilot Automated Shop Loading and Control System—CAM. Final implementation actions continuing during the period. The project is technically complete. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7707. Automated Process Control for Machining. Computer procedures for determining economical turning operations were established and demonstrated to Rock Island Arsenal personnel. Computer procedures for determining economical drilling and milling operations were designed and developed. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7724. Group Technology of Weapon Systems (CAM). A variant process planning system was developed. Implementation is scheduled. Hardware to support solid modeling was installed. A GT scheduling system was developed. A microprocessor to support this program has been ordered. A literature search was conducted. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7730. Manufacture of Split Ring Breech Seals. Design changes for automated abrasive saw have been sent to procurement. Test pieces for kinking machine tests are being manufactured. Polishing fixture has been manufactured. Specification changes have been proposed to simplify presently defined equipment. Test piece for kinking equipment tests are being manufactured. Interchangeable jaws and dual purpose table are being designed. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7753. Noise Suppressor for Powder Type Recoil Mechanism Test Machine. The noise suppressor is being modified. These modifications include extensive repair welding. A large instrumentation port was added. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7966. Manufacture of Tritium Powered Radioluminous Lamps. Testing and analysis of tritium lamp samples has been completed. Results confirm adequacy of current production methods. Process controls have been identified. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8102. Powder Metallurgy Forgings Weapons Components. A contract to establish production parameters for manufacturing split ring components has been negotiated. Various non-destructive testing techniques are being evaluated for applicability to the net shape split rings. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8103. High Velocity Machining. Project parameters are being finalized utilizing results of advanced machining research program funded by DARPA. Equipment at Mechanicsburg, PA has been identified as being potentially applicable to this program. Instrumentation is available to perform force measurements after the equipment has been installed. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8120. Adaptive Control Technology (CAM). A detailed specification to retrofit a cylindrical grinder is being prepared. If possible an existing machine tool will be used. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8243. Computer Control for Electrodeposition Systems. Definitions of input/output requirements for the new chrome plating facility

have been completed. Definition of normal component and alarm/ annunciator conditions for each state of the 120 mm/8 inch production plating facility is completed. A diagnostics simulator has been defined and acquisition of components initiated. For more information contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8244. Optimize the Heat Treatment of Rotary Forge Tubes. An analysis is being conducted of several parameters to determine their effect on mechanical properties of tubes. Differences between two tube heats is being analyzed by checking chemistry, hardenability, mechanical properties, and inclusions. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8245. Application of Erosion Resistant Low Contraction Chromium Plate. The purchase of a larger rectifier has been approved. Experiments to deposit LC chromium with a limited capacity of amperage were conducted on M68 tubes to obtain plating parameters. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 1701. Bulk Transfer of Chemical Materials. Completed collection of health and safety data. Continued analysis of current and proposed handling procedures and equipment survey. Initiated contract with AE firm to aid in facility layout. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4062. Automatic Manufacture System for Mortar Increment Containers. Project manufacture has been intensified to accelerate the equipment acceptance test schedules and to minimize the impact of the cost-to-complete proposals submitted by ESD. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4273. Automated Production of Stick Propellant. Review of die design, extrusion rate, and dry down data was continued. A pilot test line arrangement using a 4-inch press was laid out and approved to allow various cutting and handling configurations. Preliminary hazards analysis conducted. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4312. Anti-Armor Cluster Munition Production Explosive Invection. The redesign of the production prototype injection molding unit for CEMS was completed. A bid package for procuring a molding unit was prepared. Invitation for bids were issued and a vendor was selected. The injector unit is being fabricated. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4533. Lova Propellant Processing. NOS has drawn up an in-process hazards assessment test matrix. NOS initiated a literature search to compile and analyze existing in-process hazards data for lova run materials, primarily RDX and NC. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4534. XM855 Bullet Conversion of SCAMP Equipment. Cost growth requested to increase the contract value by 135K to incorporate changes requested by AMCCOM and Lake City AAP for the tip I.D. application on a SCAMP load and assemble submodule, DCAA concurred with the requested cost growth. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 4540. $CaCO_3$ Coating of 7.62 mm Ball Propellant. With the concordance of PBM, this project is now at Badger AAP instead of Olin, St. Marks, Fl., as originally planned. A revised SOW submitted in May and a contract awarded to Badger in June. SOW reduced to reflect reduction of funding. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 6599. Electro-Optical Inspection of Artillery Projectile Optical Cavity. All defect detecting electronics circuitry has been checked for proper operation and adjustments optimized. The only circuit still requiring adjustment is one that inhibits false reject signals. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 3592. Improved Graphite Reinforcement. The carbonization step and pre-graphitization step were optimized. A heating rate of 400 C produced the highest strength and modulus and the optimum graphitization temperature was found to be 1400 C. For more information, contact Sid Levine, BRDE, (703) 664-5374.

Project 3759. Kevlar Cable Reinforcement for Military Bridges. This effort is complete. It established a continuous tape lay-up method suitable for production of various width, length or load capacity tensile elements. 45 elements were tested statically and dynamically with complete satisfaction. For more information, contact Sid Levine, BRDE, (703) 664-5374.

Project 3796. Combat Vehicle Degassing. Magnetic signature data has been taken for the M1 and M60 tanks. Material samples have been given to the contractor. Data indicates that the approach used by the navy for ships and submarines will be valid for the land vehicles. For more information, contact Sid Levine, BRDE, (703) 664-5374.

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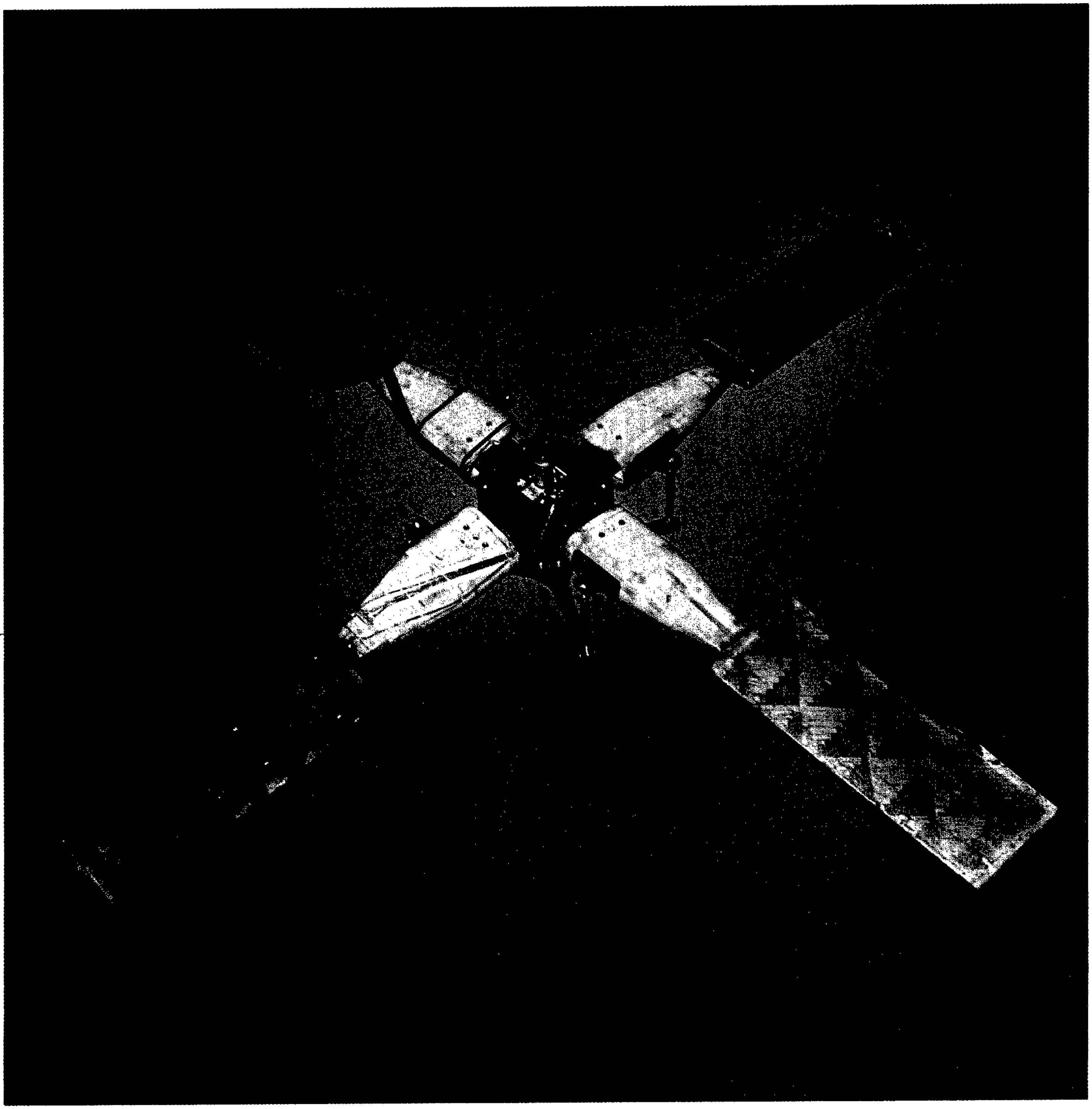

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Contents

About the Cover

Improved performance, fatigue life, and damage tolerance combine with reduced acquisition and operating costs in this composite flexbeam tail rotor (see article on page 3). Production design and manufacturing technology developed during a U.S. Army Aviation Systems Command mantech program features a low-cost wet filament winding fabrication technique and optimum composite materials. The development constitutes a low risk improvement to the Apache weapons system; two blade pairs are mounted at 90 degrees to the hub with elastomeric shear pads that significantly reduce hub loads and provide unique dynamic characteristics.

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Comments by the Editor

RAYMOND L. FARROW

One of the most significant milestones in the nearly 20 years of manufacturing technology programs of the Department of Defense has been announced since our last publication of the U.S. Army ManTech Journal. This milestone is reflected by the formal establishment of the Manufacturing Technology Information Analysis Center, a DOD agency that will be monitored by personnel from the U.S. Army Materials & Mechanics Research Center, Watertown, Massachusetts. Mr. David Seitz, who also serves as Associate Editor of the Army ManTech Journal and directly oversees most of its operation, will serve as Contracting Office Technical Representative.

Establishment of the MTIAC represents the culmination of many years of planning and discussion among officials of the Department of Defense and was a much sought after program, with over half a dozen highly reputable organizations entering bids for the project. The basic agreement entered into with Case & Co., Inc., the Chicago based winner of the competition—with support of the IIT Research Institute, calls for a minimum appropriation of $500,000 per year for the first three years with an option for two more years. Related projects could increase the size of the project to well over $1 million each year.

The objective of MTIAC's operation is to support the DOD Manufacturing Technology Program in achieving its goal of improving the productivity and responsiveness of the defense industrial base. The MTIAC will also support other government agencies and their contractors. The MTIAC will provide technical and administrative support to the DOD Manufacturing Technology Advisory Group (MTAG) and also support the private sector.

The MTIAC will serve as an authoritative information source on manufacturing technology. It will establish and maintain data bases and will be responsible for collecting, reviewing, analyzing, appraising, and summarizing available manufacturing technology data and information. The Center will provide varying products and services involving the following areas:

Handbooks and Data Books—engineering reference works containing authoritative scientific and engineering data and information.

State-of-the-Art Summaries—special studies on high interest technology.

Critical Reviews and Technology Assessments—generally exceeding the scope of a technical inquiry response but considerably smaller than a state-of-the-art summary.

Technical Inquiries—scientific and engineering analysis of available information made available via letter or telephone.

Abstracts and Index—abstracts of reports related to manufacturing technology, bound and indexed.

Bibliographic Inquiries—extracted information and references in list format.

Special Studies/Tasks—additional services such as detailed solutions to narrow scope problems, technical consultation, and logistics coordination of MTAG activities.

Acquisition and Input of Source Information—collection, review, analysis, cataloging, and storing of information on MTP investments and other pertinent literature.

User Accessible Data Base—an on-line information system accessible via telephone.

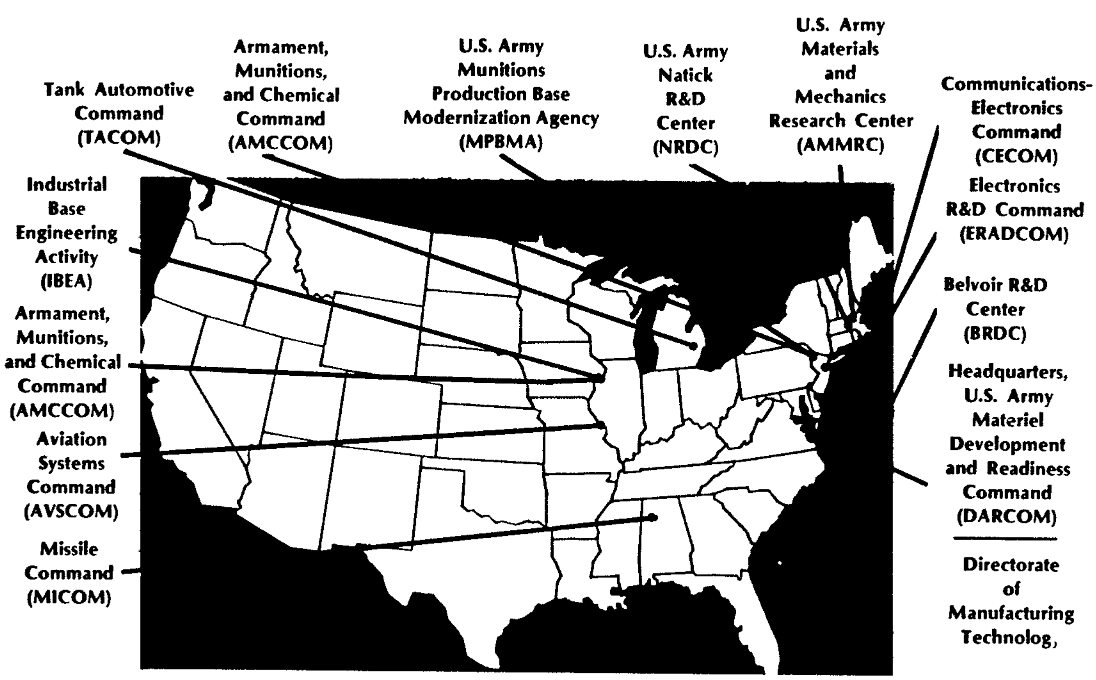
Current Awareness Program—recurring newsletters highlighting current affairs in manufacturing.

The Center comes at a time when the body of information generated through the years by the mantech program is increasing in archival importance and new data is being acquired at a record pace. This publication has served since its inception 8 years ago both the Department of Defense and industry as the most comprehensive focused source for U.S. Army manufacturing accomplishments, but the Center will provide a new, broader perspective of manufacturing technology, both in the defense and industrial sectors.

The manufacturing technology program recently has drawn most favorable comments from industry media and currently enjoys the confidence of high officials in government. The Center should further enhance this perception.

The MTIAC is scheduled to begin operations late in 1984. Additional information is available from David Seitz, U.S. Army Materials and Mechanics Research Center, AUTOVON 955-5527, Commercial (617) 923-5527; or the MTIAC Director, Thomas Turner, Case and Company, (312) 567-4730 or (312) 861-0994.

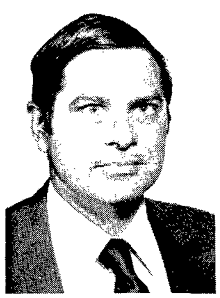
DARCOM Manufacturing Methods and Technology Community



Performance, Fatigue Life, Damage Tolerance Better

Composite Flexbeam Tail Rotor Practical

SEYMOUR H. WIESENBERG is an Industrial Engineer at the U.S. Army Aviation Systems Command with the Project Manager's Office for Tactical Airborne Remotely Piloted Vehicles. He was the PE on the program that developed the composite flexbeam tail rotor while assigned to the AVRADCOM Manufacturing Technology Program. During his 15 years of industrial experience, he was heavily engaged in quality engineering at General Electric before joining the Government engineering staff. He received his B. E. in Industrial Engineering from New York University and his M.B.A. from the State University of New York at Buffalo.



Fabrication of a successful flexbeam tail rotor by the U.S. Army Aviation System Command has been possible through use of a wide range of state-of-the-art composite manufacturing techniques, with emphasis upon automated wet filament winding. Techniques included manual layup and wet filament winding; vacuum bag, internally pressurized split mold, and autoclave curing; and disposable foam mandrel, plaster, steel, and high temperature epoxy tooling.

The objective of this project conducted by Hughes Helicopters, Inc., was to refine and verify the manufacturing processes and production configuration for a composite flexbeam tail rotor for the AH-64 Apache Attack Helicopter. The program was structured to consist of design refinement, manufacturing methods development, tooling development, fabrication of test components, structural laboratory tests, and wind tunnel testing.

When fully implemented, the composite flexbeam tail rotor will provide several important benefits including:

- Improved tail rotor performance
- Reduced acquisition cost
- Reduced operating cost
- Improved fatigue life
- Reduced parts count
- Improved damage tolerance/survivability.

The composite flexbeam tail rotor development effort follows the modern trend to incorporate advanced composite structures in ever increasing applications in Army aircraft to realize the advantages of decreased weight and life cycle cost. The wet filament winding cocure process has been demonstrated as a viable approach for reducing labor requirements in the construction of composite

NOTE: This manufacturing technology project that was conducted by Hughes Helicopters was funded by the U.S. Army Aviation Systems Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Bill Brand, (314) 263-3079.

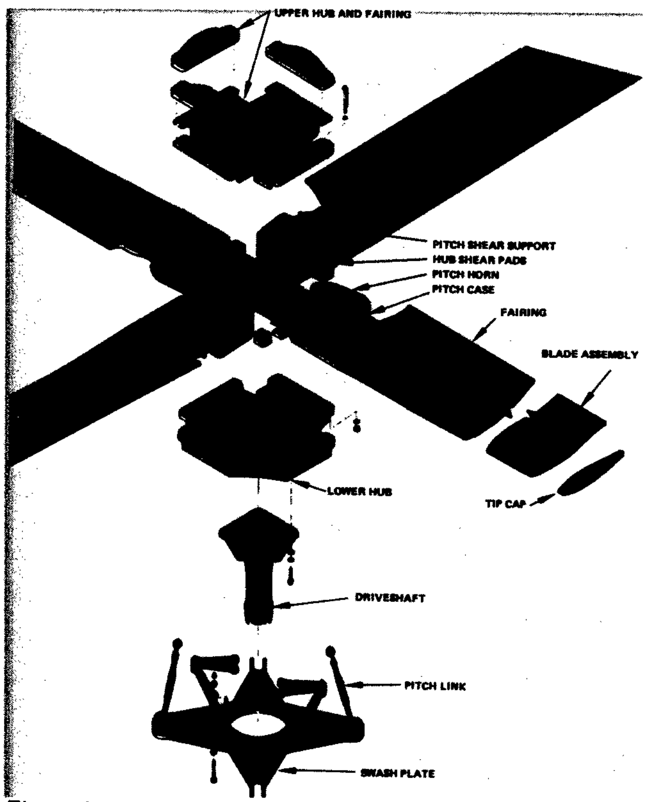


Figure 1

components while utilizing raw materials at their lowest cost and providing a repeatable/reliable structure.

Hughes Helicopters designed and built a full-scale prototype bearingless tail rotor under an independent research and development program and verified the concept in a 10-hour whirl test in mid-1979. This MM&T program further refined the design and manufacturing technology to be fully compatible with the production Apache helicopter.

Kevlar Used in Blades

The composite flexbeam tail rotor was designed in accordance with all structural and environmental requirements for the metal tail rotor blade. Compatibility with the GE-T700 increased performance engine also was required. A ± 5 degree glass fiber/epoxy flexbeam connects the wet filament winding Kevlar/epoxy blades to the hub, within which elastomeric shear pads allow the flexbeam to bend freely. A pitch case transfers pitch control loads into the blade, and shear supports center the pitch case about the flexbeam. The Kevlar blade is of wet filament wound tubular construction. This design was shown analytically to have good dynamic characteristics and to be free from aeroelastic instability.

An exploded view of the composite flexbeam tail rotor (Figure 1) shows that the spanwise axes of the blade-pair assembly are perpendicular to each other and are separated axially so one flexbeam may cross over the other. The rotor has upper and lower hub plates which sandwich the blade-pair assembly. The hub assembly is bolted to the tail rotor drive shaft. The flexbeam extends from one blade across the hub to the opposite blade. Bending and twising motion of the flexbeam between the edge of the hub and the inboard end of the blade provides the fundamental flap, lag, and torsional motions of the rotor blades. The flexbeams are attached to the hub plates through elastomeric shear (in-plane) pads. These pads are bonded to the flexbeam on one side and are mated to the hub through the clamping bolts. The pitch case transmits pitch link (feathering) motion to the blade. The laminated elastomeric pitch shear support aligns the pitch case with respect to the flexbeam. The pitch horn is bolted to the trailing edge of the pitch case. The spanwise location of the pitch link attachment is designed for an effective pitch-flap coupling of -35 degrees (pitch down with flap up). The pitch link is inclined to provide negative pitch-lag coupling (pitch up with blade lag). The rotor diameter is 112 inches and its blade chord is 11 inches, which includes a trailing edge tab of 1.1 inches. The blades have an NACA HH-02 airfoil at the tip, transitioning to a modified 17 percent thickness HH-02 airfoil at the root.

Design Ground Rules

The criteria and requirements that directly influenced the composite flexbeam tail rotor design are as follows:

(1) Adopt rotor blade external geometric properties for optimum performance for the GE-T700 engines.

(2) Design for compatible dynamic operation on the AH-64.

(3) Design, as a minimum, to existing metal tail rotor blade reliability and maintainability requirements. Place strong emphasis on a high level of field repairability.

(4) Select and use nonmetallic structural filaments stabilized in an epoxy matrix to the maximum practical extent.

(5) Design for a fatigue life of 4500 operating hours.

(6) Design every part to be invulnerable to a tumbled 12.7 API projectile strike. The rotor shall be capable of continued safe operating 30 minutes after the strike.

Significant differences in geometry between the metal tail rotor and the composite flexbeam tail rotor existed. First, azimuth blade spacing is 55 degrees for the metal tail rotor and 90 degrees for the composite flexbeam tail (as shown in Figure 2). The 55-degree configuration was originally chosen to minimize disassembly for air transportability. But the stretched version of the C-141 transport no longer requires a folding tail boom and 55 degree tail rotor. Second, the axial spacing between composite flexbeam tail rotor blade pairs is 0.65 inch, compared to the 4.90 inch spacing of the double teetering

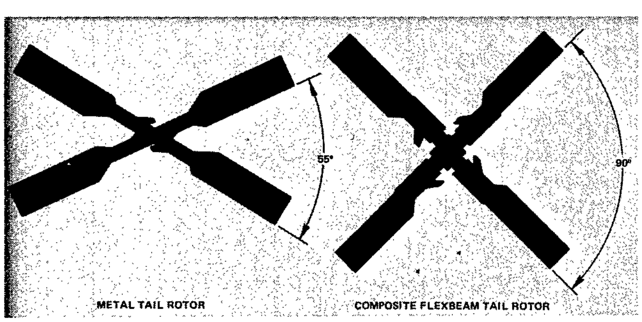


Figure 2

metal tail rotor. The 55-degree spacing of the metal blades required enough axial separation to avoid blade/pitch horn interference. The 90-degree spacing allows closely stacked flexbeams and a more compact hub design. Third, the pitch horn attachment was changed from the leading edge as in the case of the metal rotor to the trailing edge for this rotor. This change assured positive stability over the collective pitch range and eliminated a 3/rev resonance in the second chordwise bending mode. However, when diameter and chord of the rotor were increased to 112 inches and 11 inches, respectively, from the Phase II metal tail rotor diameter of 110 inches and chord of 10 inches. This change was made to provide increased tail rotor thrust for controllability of the AH-64 with the more powerful T700 engines.

Higher control loads result from a larger rotor; this would have been incompatible with the tail rotor control system. So the existing airfoil was changed to an HH-02 section at the tip, varying linearly to a similar 17 percent thick airfoil at the root. At the same time, the tab angle was changed from +6 degrees (trailing edge down) to 0 degrees. The combined result was acceptable control loads and an improved controllability ceiling.

Lightning, Ballistic, and Erosion Protection

A qualitative rotor vulnerability study was performed comparing the current design of the rotor with the baseline AH-64A metal design. The vulnerable area due to impacts by 12.7-mm API projectiles may be totally eliminated upon validation of the flexbeam detail design. If so, an invulnerable tail rotor would decrease the vulnerable area of each ship due to the 12.7-mm API threat by 16 percent compared to the baseline design. The vulnerability attributed to the 23-mm HEI threat can be expected to decrease by a minimum of 10 percent, due primarily to the less critical blade balance weight location on the pitch case rather than at the tip on the metal tail rotor.

The major portion of the vulnerable area reduction would be accomplished by demonstration that the flexbeam within the hub area is tolerant to the worst case

penetration damage of an armor piercing projectile. Due to the hub design of the composite tail rotor, parts or all of the swashplate assembly are not ballistically critical. The blades are also invulnerable due to the effect of its large size. The pitch links are lightweight members designed only for flight loads—API strike loads are not considered. It has been demonstrated with flexbeam rotors that when a pitch link breaks, its blade twists back to near zero lift condition and remains stable. Hence, armored pitch links are not necessary.

The criteria applied in the design for lightning protection of the composite flexbeam tail rotor included the following ground rules:

- Repairable damage from strikes up to 50,000 amperes
- Ability to return to base after 200,000 amperes strike
- No significant cost penalty
- No significant weight penalty.

Lightning tests conducted as part of a company funded program on subscale components representing rotor blades and fuselage structure—fabricated from Kevlar, glass, and graphite epoxy materials—have established an understanding of the effect of lightning on composite structure. In the case of a structure fabricated from nonconductive material such as glass or Kevlar, strikes will circumvent the structure even when placing the electrode almost in direct contact with the structure surface. However, the conductive material buried within the structure (such as balance weights) attracts lightning, and if not properly grounded will cause significant damage.

With the exception of the leading edge steel rod balance weights and the steel erosion strip, the rotor is completely nonconductive. Therefore, it was recommended that no additional protective material such as metallized wire mesh screen be required for lightning protection. All metallic material substructure such as the balance weights and backing strip will be properly grounded to the hub.

Polyurethane was selected to protect the rotor leading edge from sand and rain erosion for the following reasons. First, although its resistance to rain is poor relative to nickel (another good antierosion material), an inordinate amount of rain for an unusually long period of time is required for erosion to occur. Next, the cost per blade is small and it can be repaired or replaced easily. Last, it is used successfully on the CH-53 main and tail rotors and Westland WG-13 main rotor blades.

In the event of premature loss of the polyurethane strip, a preformed 0.015-inch stainless steel strip was added below it in the high erosion rate, outboard area only of the leading edge.

Structural Analysis

The structural integrity of the rotor was established analytically and verified later by a series of laboratory static and fatigue tests. Specifically, analytical static and fatigue substantiation of the AH-64 system included design criteria, material allowables, calculated minimum margins of safety, and summary analyses of structurally critical areas. Based on this analysis, there will be no failure at ultimate load (1.5 x limit load), negligible permanent set under limit load, and the fatigue life will be equal to or greater than 4500 hours, the design life of the AH-64. In addition, with a failed critical structural element (e.g., one bolt in a 4 bolt joint), the composite flexbeam tail rotor will be capable of taking limit loads as ultimate, without further failure.

Design loads were calculated from the AH-64 flight spectrum. An unbalanced blade strike load of 2395 pounds is derived from the condition whereby the outer 10 percent of one blade is sheared off. This load was minimized by terminating the steel leading edge rods at a point which is 90 percent of the blade radius. Vulnerability, ground, and weapons blast loads are relatively small and did not influence the design.

The static, mechanical, and physical properties of ±5 degree S-2 glass/epoxy and unidirectional Kevlar/epoxy, the two primary composite materials in the rotor, were obtained. Tension and shear fatigue allowables were obtained from Hughes test data, published data, and the con-

struction of Goodman diagrams. Figure 3 is a graph of the axial, flapwise, chordwise, and torsional stiffnesses of the flexbeam. Pitch case, blade axial, flapwise, chordwise, and torsional stiffnesses were also calculated.

A listing of analyzed components and associated minimum margins of safety were compiled. The margin of safety for both metallic and composite parts is based on ultimate loads, which are 1.5 times limit load. The most critical area is the flexbeam/pitch case joint, with a static margin of safety of 0.09 and fatigue margin of 0.02.

Manufacturing Development— A Building Process

Fabrication of the composite flexbeam tail rotor involved a wide range of state-of-the-art composite manufacturing techniques, including manual layup and automated wet filament winding of the composite materials; vacuum bag, internally pressurized split mold, and autoclave curing; and disposable foam mandrel, plaster, steel, and high temperature epoxy tooling. Composite blade manufacturing experience at Hughes Helicopters was based initially on the Multi-Tubular Spar (MTS) program and the Composite Main Rotor Blade (CMRB) program for the AH-64. Integration of this experience into the rotor design began when Hughes fabricated a full-scale prototype rotor using simplified plaster tooling and, for the most part, manual layup of composite materials. Then, during the MM&T program, improved tooling was fabricated, wet filament winding and other processing refinements were instituted, and detailed records of labor and material costs were maintained for future learning curve and cost reduction analyses. An overall flow diagram of the assembly sequence is presented in Figure 4.

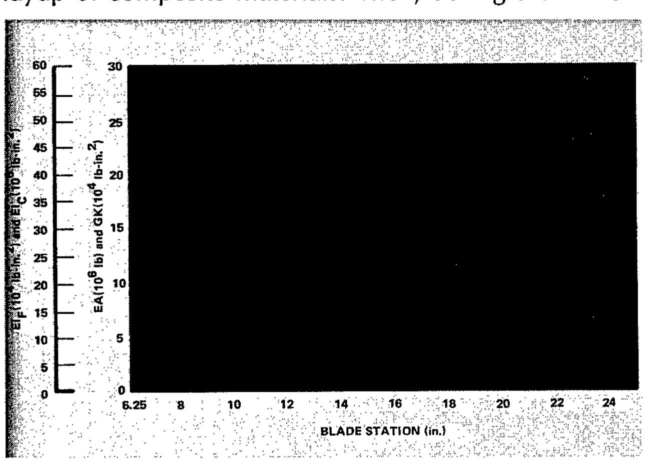


Figure 3

Quality Assurance acceptance criteria were prepared to verify that each component was produced according to engineering drawings, specifications, and production documents. Major areas for which test plans were implemented included:

- Receiving inspection for materials
- Resin preparation and wet filament winding
- In-process assembly and final inspection
- Nondestructive (light-through transmission, ultrasonics, and X-ray) inspection.

All test results were recorded and have been maintained so that maximum future benefit may be realized from this development program. Lot or batch number of materials used in each tail rotor were recorded. Equipment and gages used to control or measure materials and processes were periodically calibrated according to Hughes Helicopters' calibration procedures and were approved by Army personnel.

Coupon/Element Test

The two critical areas tested with full-scale components were the flexbeam root-end and flexbeam/pitch case attachment area. In addition, numerous coupon tests were conducted to determine the physical, static, and fatigue properties of materials used and the strength of primary bonded joints.

The selected flexbeam material, NARMCO 5216 S-2 glass prepreg, was qualified to the appropriate Hughes Helicopter material specification. In addition to these standard tests, which included tensile tests of coupons with 0 degree fiber orientation, tensile and interlaminar

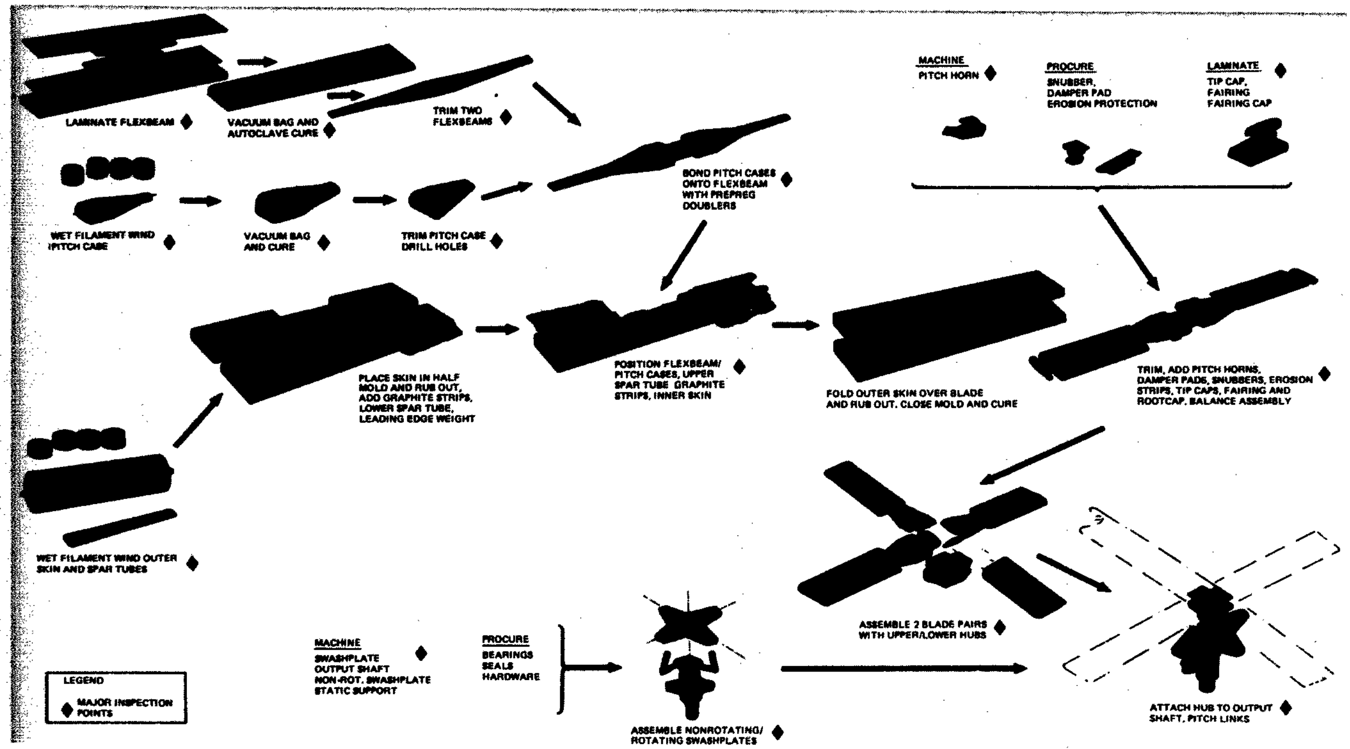


Figure 4

shear tests were conducted on ± 5 degree fiber orientation coupons. The ± 5 degree tensile test specimen is shown in Figure 5. The width was varied to observe its effect on tensile strength, since a relatively narrow specimen will have fewer continuous fibers extending between the two tabs than a wider one. Results of these tests were plotted. The short beam shear specimen was in accordance with ASTM 2344 except for width, which was increased to 0.5 inch to increase the percentage of full length ± 5 degree fibers. The results are indicative of a high quality laminate.

The tension fatigue strength allowable of the ± 5 degree S-2 glass/epoxy flexbeam material was determined experimentally by testing seven coupons. One set of four coupons was fabricated with Composites Horizons CH3060 resin system and a second set of three coupons used the APCO 2434/2347 resin system.

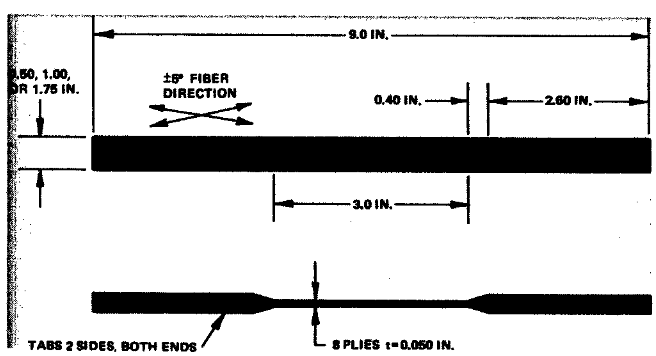


Figure 5

Physical property determination of the flexbeam was an important parameter, both in the early stages of matèrial selection and development and during the fabrication of each flexbeam. The material selected was NARMCO 5216 S-2 glass unidirectional prepreg, rather than S-2 glass wet

filament winding in-house with APCO 2434/2347 resin system because of better handling qualities and more consistent resin content. Laminate fiber volume was initially targeted at 60 + 3 percent in order to maximize tensile strength.

Two sets of test panels, one set with 6 or 7 plies simulating the thinnest outboard region of the flexbeam and the other set with 66 to 80 plies that simulate the thickest root-end area of the flexbeam, were autoclave cured with varying numbers of bleeder cloths. The fiber volume of the thin panels was about 62 percent, but the thick panels maintained a fiber volume of about 55 percent. The reason for the lower fiber volume was the incomplete resin bleedout from the interior of the thick laminate prior to resin setup. Since the strength of the laminate was still adequate, two-third scale (in length only) flexbeams were fabricated. Thinner areas of the subscale flexbeams had acceptable fiber volumes, while the full thickness (0.57 inch, 68 ply) areas had an average fiber volume of 54.88 percent. During the course of full-scale flexbeam fabrication, physical property specimens were taken from the midsection of the laminant between each flexbeam.

Joint Shear Strength Checked

A second series of coupon tests investigated the shear strength of the joints between (1) the flexbeam and pitch case doubler and (2) the flexbeam and spar tube. The substrates were designed and fabricated to simulate the respective full-scale structures as closely as possible. The double lap was varied to give a 0.5, 1.0, and 1.5-inch length to determine its influence on structural efficiency (average shear strength).

The adhesive for the pitch case doubler/flexbeam joint was Hysol EA 9528, while the spar tube substrate was cocured without adhesive to a precured flexbeam substrate. Similar pitch case doubler/flexbeam specimens made with ±5 degree S-2 glass fiber and APCO 2434/2347 resin system were also tested for initial evaluation and comparison. Except for one data point, the adhesively bonded prepreg substrates appeared stronger than the cocure system. This fact, combined with its handling ease during layup, provided the basis for selection of the prepreg for the pitch case/flexbeam doubler. The average shear strength of four flexbeam/spar tube, 0.5 inch long shear specimens was 2269 psi.

Wind Tunnel Tests Performed

Wind tunnel tests were successfully performed to verify the performance, loads, and dynamic characteristics of the design for rotor speeds up to 100 percent of design operating rotor speed and airspeeds up to 197 knots. A complete pitch range was investigated in hover, low and high speed forward flight, and sideslip conditions.

An assessment of composite flexbeam tail rotor characteristics from the voluminous amount of data gathered during the wind tunnel test was categorized as follows: performance, structural fatigue, dynamics, and blade loads. Correlation of test data is made with analytical predictions and load limits of structural components wherever possible. But because the design was tested as an isolated rotor system without the blockage effects of the AH-64 vertical tail, the various test conditions cannot be directly correlated with predicted flight cases.

A comparison of the measured collective pitch angle at 75 percent radius with thrust coefficient versus the theoretically predicted collective pitch angle shows higher pitch angles required to produce the same thrust when compared to the predicted pitch angles. This has been the case in previous comparisons with measured full scale main and tail rotor data. Part of this pitch difference may be in the zero lift pitch angles of the test rotors. Further investigation will be required to resolve the difference in pitch angles.

Structural Fatigue Determined

The structural evaluation was limited to the comparison of measured loads with the endurance limit and the 1-hour limit established for each structural member. These are the same alternating load or stress limits used as criteria to monitor the rotor structural response during the wind tunnel test.

One or both of the monitoring limits were exceeded

in a few test conditions. These occurrences are primarily useful to indicate areas for additional investigation which are beyond the scope of the present work. For example, it needs to be determined whether each test point which produced excessive alternating load lies within the actual flight envelope. If so, its frequency of occurrence within the total spectrum of flight loads would need to be determined in order to assess its effect on the service life of the affected structural member.

Flexbeam test stresses due to flapwise and chordwise bending were well below the endurance limit except at one point where 8.5 degrees right sideslip at 197 knots produced an alternating corner stress 30 percent greater than its endurance limit but 14 percent less than the 1-hour limit. However, it should be noted that the corner stress is based on the conservative assumption that flapwise and chordwise moments peak simultaneously.

Pitchlink test axial load exceeded its endurance limit at speeds above 161 knots and its 1-hour limit above 190 knots. These pitchlink load limits were actually used to monitor the pitchhorn. A minor modification of the pitchhorn would raise both limits well above the test loads measured. Rotor mast test bending moment reached 99 percent endurance limit at 197 knots. If needed to satisfy actual flight envelope requirements, minor dimensional modifications would increase this margin. The output driveshaft test bending moment did not exceed 51 percent endurance limit. Upper and lower hub test stresses did not exceed about 6 percent endurance limit.

Future Work

The MM&T program successfully developed a production design and manufacturing technology for the Apache helicopter flexbeam tail rotor. Fabrication techniques incorporated low-cost wet filament winding and an optimum amount of composite materials. The design and analysis were confirmed through laboratory and wind tunnel testing. The conclusion is that the composite flexbeam tail rotor can be a low-risk improvement to the Apache weapons system.

It is recommended that future work be initiated in accordance with the Airworthiness Qualification Specification, which includes an analytical evaluation of the composite flexbeam tail rotor on the Apache; laboratory, flight, and environmental tests; and modifications to the Apache helicopter required for composite flexbeam tail rotor implementation.

Significant Payback in Life Cycle Costs

Low Cost, Reliable Electromagnetic Components

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Electromagnetic component manufacture took a quantum leap technologically as a result of a U.S. Army Missile Command MMT project that has been done by Hughes Aircraft. A multitude of new techniques for the manufacture of low cost, high reliability core type transformers/inductors for missile system applications were examined and evaluated. Molding technologies, winding techniques, curing procedures, and encapsulation processes were topics considered in extreme detail. Over 40 encapsulation thermosetting compounds for high reliability components were investigated, with two selected for their low stress and high voltage, corona free applications, respectively.

The Phase I effort concentrated on improving the manufacturing methods of potting, encapsulation, and winding of electromagnetic devices, while the follow-on phase (Phase II) investigated interconnection techniques, tooling, and structural parts. Implementation of the combined results of both of these efforts should improve manufacturing methods for electromagnetic components so that a significant payback will be obtained in manufacture and life cycle costs of missile systems due to lower production costs, higher process yields, and improved reliability.

Methods of Potting/Encapsulation

An in-depth investigation of over 40 encapsulation compounds was made to identify those which would have the optimum parameters for encapsulation or potting of electromagnetic components for missile applications. Proposed values of 36 parameters were established, against which each compound was evaluated. In many cases data

NOTE: This manufacturing technology project that was conducted by Hughes Aerospace was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Bobby Austin, (205) 876-2147.

was not available from the vendor, so tests were made to obtain the required information to facilitate comparison. One of the most critical parameters is the glass transition temperature of the resin, below which many materials exhibit a rapidly rising compressive stress. Such stresses applied to strain sensitive cores during temperature cycling can adversely affect the functional response of magnetic components. A direct measurement of these stresses, ranging as high as 6000 psi at −40 C, was made using pressure calibrated mercurial thermometers. A two-step process, using soft material first to cushion the core from the stresses generated by the final material, was investigated. This method showed some reduction, but was not comparable to the low stress materials evaluated.

As would be expected, no one resin was a universally ideal encapsulation material. Trade-offs of parameters and properties are required for each application. The five materials which were judged to have the most acceptable combination of parameters, including compressive stresses of less than 200 psi at the lowest temperatures, were Epon 825 with HV hardener; Scotchcast 255; Eccoseal 1218; Hysol C-60; and Hysol C15-015. As an example of the trade-offs only, the Epon 825/HV was corona-free during high voltage tests; the other four had varying degrees of corona present. On the other hand, for low voltage applications under 250 V peak, some of the others had more optimum parameters. This information would assist the designer in making the proper selection of encapsulating material for a high reliability magnetics application and also help the manufacturer in setting up the proper processing and handling procedures to produce a cost effective, reliable part.

Special Considerations

It is recommended that a standard set of test conditions to obtain the required data for new resins should be established to allow comparison with existing materials for high reliability applications, especially for determination of electrical properties. Mechanical and thermal properties are covered fairly well by ASTM procedures. Further, a major source of failure in encapsulated magnetic components wound with fine wire is breakage of the leads between the coil and the terminals caused by thermal expansion of the resin. Intermediate leads of AWG 36 or larger should always be used. The test assembly used in this work is shown in Figure 1.

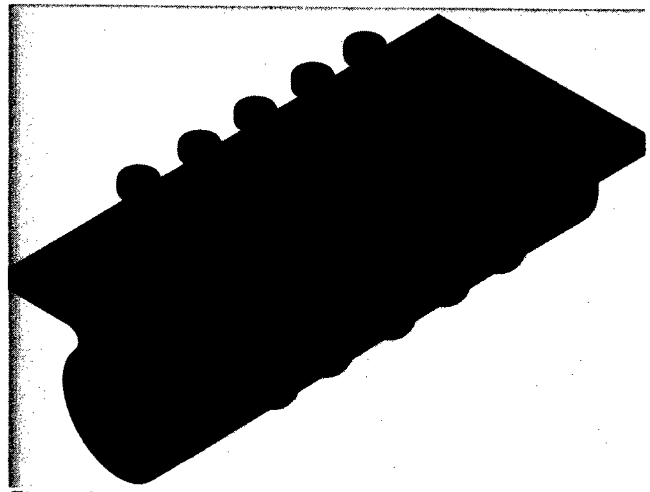


Figure 1

Pressure sensitive magnetic cores and other fragile electronic components require low stress potting/encapsulation techniques and materials. Quantitative measurements of stress as a function of temperature are needed to properly evaluate a material.

A method of hydrostatically stressing small magnetic components to 10,000 psi was also developed. Ferrites, moly permalloy powder (MPP), and tape would cores were exposed to this pressure level, with very small effects. Later tests showed that unbalanced rather than isotropic stresses significantly altered the magnetic properties.

Conap EN-9, Conap EN-9-OZR, Uralane 5753, RTV 615, RTV 619, RTV 627, and RTV 655 showed less than 200 psi at −40 F, with no apparent glass transition temperature reached. The use of a high stress material over a low stress encapsulant to reduce the overall stress generated was partially successful, but was far from the 200 psi arbitrary limit selected as acceptable.

Finally, for high voltage applications, Epon 825/HV was the only material that showed zero corona level. Scotchcast 255 and Eccoseal 1218 had high corona levels at the same applied voltage, although their dielectric strength was sufficient to prevent short-term breakdown.

Controlled Winding Techniques

The controlled winding techniques task addressed four areas: wire handling, contamination, solenoid and transformer coil (bobbin) winding, and toroidal coil winding. The obvious observation that, in order to produce a reliable component, the materials being used must be of

highest quality, is doubly true for the wire used in winding electromagnetic components. The wire handling and contamination investigation concluded that spools of wire, especially the fine and ultrafine gauges, should be encased at all times in foam plastic protective enclosures and inserted into plastic bags, except when wire is being removed at the winding station. The smaller sizes of wire are especially susceptible to damage from dropping, which damages the spool, and objects striking the wire, interfering with the unwinding process. Exposure of the unprotected spool to contaminants of any kind—either airborne or liquid splashes—or handling without gloves will degrade the encapsulation process. Yet it was interesting to note that no such precautions were taken in any facility that was visited. In most cases the spools of wire were stacked in open stockroom areas without any protection whatever.

An analyisis of the tension factors involved in winding many layers of ultrafine wire on square bobbins, followed by fabrication of actual coils using normally accepted tension figures, revealed a cumulative wire and insulation deformation effect which apparently has not been reported in the literature. Using accepted tension levels of the industry which are calculated to stress the ultrafine wire well under its elastic limit, a buildup of internal radial pressure (IRP) at the corners of the bobbin was sufficient to compress the insulation tightly together, eliminating all voids; also, plastic deformation and flow of the copper occurred. Slippage or cleavage planes of groups of conductors through the winding was also seen in sectioned coils. The analysis showed that the factors involved were the winding tension, wire diameter, numbers of layers, and initial radius of curvature of the corners of the bobbin. Tensions less than 42 percent of rated were required to prevent this damage. Rounding the corners of the bobbin sufficiently will reduce the IRP and achieve a damage-free winding. No problem exists if a round bobbin is used at standard winding tensions.

Anomalies Encountered

A hidden source of wire damage was also uncovered in the toroidal winding investigation. Realizing that a certain amount of skill is required of winding personnel in positioning the toroid so that the shuttle does not scrape the insulation from the windings already on the toroid, a method of detecting this possible damage was proposed. An alarm circuit (Figures 2 and 3) was developed

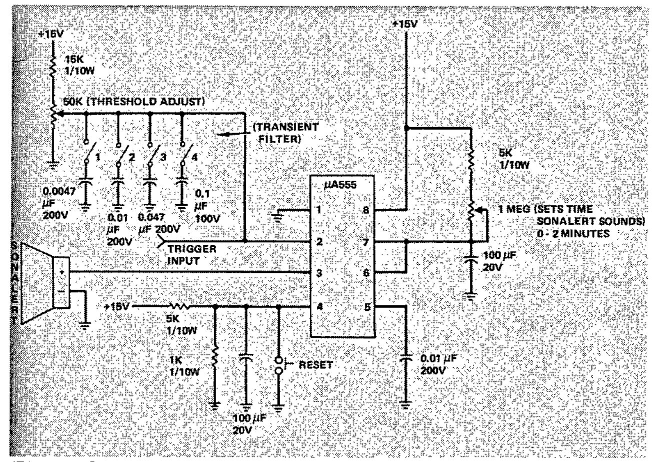


Figure 2

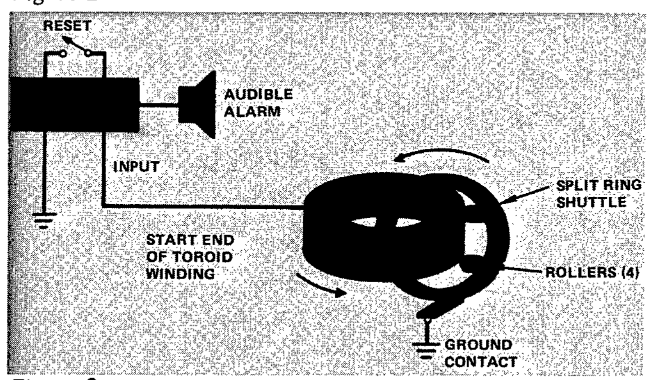


Figure 3

which would detect a momentary electrical contact between the shuttle and the wire it carried. For higher reliability components it is proposed that tripping of the alarm during winding would be cause for rejection, thus saving the cost of further manufacturing a defective part.

An additional benefit of the device was found to be a continuous monitoring of wire insulation integrity, not before possible. Conventional QA acceptance of fine wire is to take a few feet off the end of the spool and perform the requisite tests, assuming that this is representative of wire quality throughout the spool, which may or may not be true. During the development of the circuit, while winding toroids, the alarm was tripped several times with no obvious contact of the shuttle and the windings. Since the wire being used was from an old spool, it was scrapped and a new spool substituted; the problem went away. When the cause was finally pinpointed as probably due to defective wire, the old spool had been discarded and was not available for confirmation.

When toroidal windings were being made for the MM&T program, another anomally was encountered, in that the alarm would trip randomly. Since this time the wire insulation quality was nominal, the cause was traced to the shuttle ring itself. The split in the shuttle ring which accommodates the toroidal core was found to scuff the insulation of the fine wire during the loading and subsequent winding operation to the extent that not only was the insulation penetrated, but sometimes a notch was made in the copper itself. A small piece of tape placed across the split prior to loading of wire corrected the problem, which apparently is not done in usual practice or required in general winding specifications.

From the above it is concluded that such a monitoring device used on all toroidal winders would improve the reliability and reduce costs by early detection of damage and localization of problems for all sizes of wire.

In conjunction with the bobbin and toroidal winding investigations, a study of the various methods of wire tension control was made. Such devices have been in use for many years, with no new approaches found applicable to fine wire. Also included is a suggested check list for setting up a toroidal winder for fine wire winding.

Interconnection Techniques

Five different areas were covered during the project, namely, stripping of wire insulation; techniques for joining ultrafine coil wires to intermediate lead wires; size requirements for intermediate leads; techniques for terminating ultrafine wire; radii of connections as a function of operating voltage, including methods of making low cost, reliable connections in high voltage components.

A survey of the various methods to remove magnet wire insulation, which included heat, abrasive, laser, and chemical, was made and compared. No clearcut method of insulation removal was found that did not have significant disadvantages.

A method investigated which appeared very promising at first was the removal of the insulation by a stream of abrasive particles propelled by a small air blast (Figure 4), which removed insulation readily including the high temperature ML materials. Initial tests run on large wire sizes showed an effective removal of insulation without eroding the copper conductor itself. Nozzles were designed to impinge fine wire on all sides so that it would not have to be rotated to completely remove the insulation;

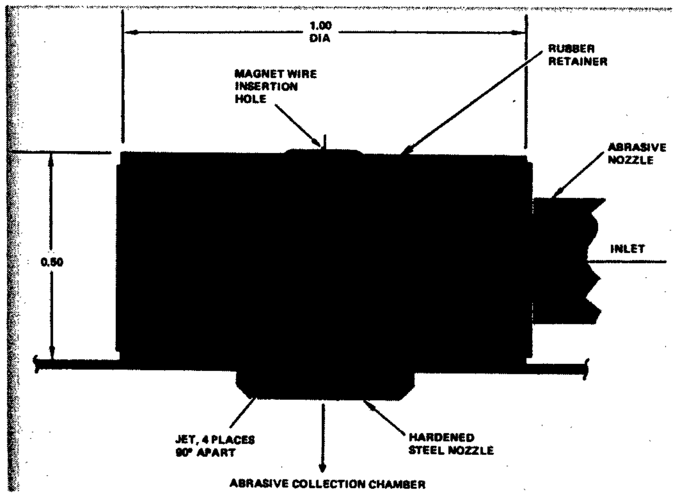


Figure 4

however, adverse effects on solderability and mechanical properties caused further work to be discontinued. Insulation removal with the carbon dioxide laser showed promise with the larger wire sizes, but further work is required for application to fine wire gauges in a production environment.

Various techniques for connecting fine and ultrafine magnet wires to intermediate lead wires were investigated. As a general rule, wire sizes smaller than AWG 36 should not be routed through encapsulation materials for any great distances, because the thermal expansion of the material can cause breakage. The normal procedure is that, after winding a fine wire or ultrafine wire coil, the insulation is removed and an intermediate lead wire soldered in or otherwise connected and the resulting joint taped down on the winding. The intermediate wire then goes to the terminals to connect to the outside world.

Since tin-lead solders are capable of dissolving fine copper wire during the soldering operation, other solder formulations were investigated. Also, other methods of achieving a low resistance joint (Table 1) were investigated, such as welding, laser welding, crimping, and the use of conductive adhesive materials. The conclusion was that careful control of all soldering parameters, including soldering temperature, time, and size of the iron, would allow joints to be made with fine wire without significant dissolution using conventional tin-lead solders.

During encapsulation of high voltage transformer windings, extensive care is taken to prevent the occurrence of voids, which are a source of corona causing progressive

Attachment Process	Material	Number of Samples	Joint Resistance (ohms)		
			Min.	Max.	Avg.
Solder Alloy	50% Indium, 50% Lead	10	0.022	0.053	0.040
	25% Indium, 75% Lead	7	0.015	0.064	0.041
	20% Tin, 80% Lead	9	0.030	0.065	0.046
	10% Tin, 88% Lead 2% Silver	7	0.010	0.080	0.068
Conductive Adhesive	Eccobond 56C	9	0.056	0.099	0.080
Crimping	Lead Foil	8	0.089	0.50	0.21
Laser Welding	Magnet Wire	1	Not Tested		

Table 1

degradation of the insulation material. It is also considered imperative to eliminate any sharp points which may occur in the high voltage gradient regions. What has not been appreciated previously is that a sharp point in the high voltage winding can have a high enough voltage gradient to actually create voids in insulation where none originally existed. Once this void is created, the insulation begins to fail progressively, forming "trees." It was found that, when using diagonal cutters or scissors in cutting fine wire, the resultant sharpness of the cut increases the voltage gradient into the region where voids can be generated with only a moderate amount of high voltage applied to the winding. Caution must be especially taken in the termination of fine wire to the intermediate lead wire interface. A method of solder balling or putting a conductive sphere over the joint to control the gradient was investigated (Figure 5).

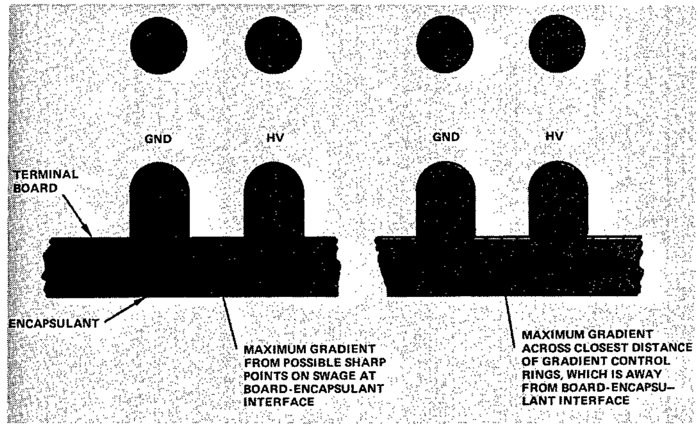


Figure 5

Tooling and Equipment for Encapsulation

This work addressed three areas: evaluate equipment and tooling to encapsulate devices with the processes developed in the basic program; determine the feasibility of automatic mixing and metering equipment; implement a continuous process for potting and encapsulation. A multiwinding, high voltage toroid with some windings using fine wire, and a high voltage biased, two-coil inductor with a C-core (Figure 6) were selected from missile programs as being typical components. Depending on the quantities involved, various molding systems were investigated, ranging from low production of a few hundred per month to high production of ten thousand or more per month. A major constraint in the design of the molds was that it was to minimize hand labor in the finishing and that the mold was to provide the outer surface of the component, as potting cups or covers were to be used. With the small and medium production runs, slush-type molds of low melting temperature metals which could be melted down and recast and silicone rubber molds were developed. The normal cure process requires these molds to be placed in a pressure vessel and held at 500 psi for 16 hours to eliminate voids. The silicone rubber molds allowed the substitution of a 5 to 10 minute centrifuging immediately after pouring to displace the bubbles, then cure in a simple temperature chamber instead of a pressure chamber for 16 hours. Another approach involved the use of aluminum molds of simple construction which would allow the encapsulation material to be introduced under vacuum and pressurized at 500 psi, then the mold would be disconnected and placed into the temperature chamber. Each mold was its own pressure vessel. For high production rates using technology in other industries, a liquid injection mold (LIM) process (Figure 6) was investigated for both the dual coil conductor and the toroid. Acceptable parts with a minimum of hand labor—very consistent in quality—were obtained, but the production rate was limited by the long cure time of the Epon-825/HV hardener used. A material with a faster cure time meeting all of the other parameters required would greatly enhance this method of encapsulation.

Automatic mixing and metering equipments were investigated and typical equipment obtained to evaluate operation in low-to-medium production operations. This would substitute for the hand labor usually used in mixing up batches of encapsulation material prior to pouring. The equipment evaluated allowed the resin and hardener to be maintained under vacuum and introduced

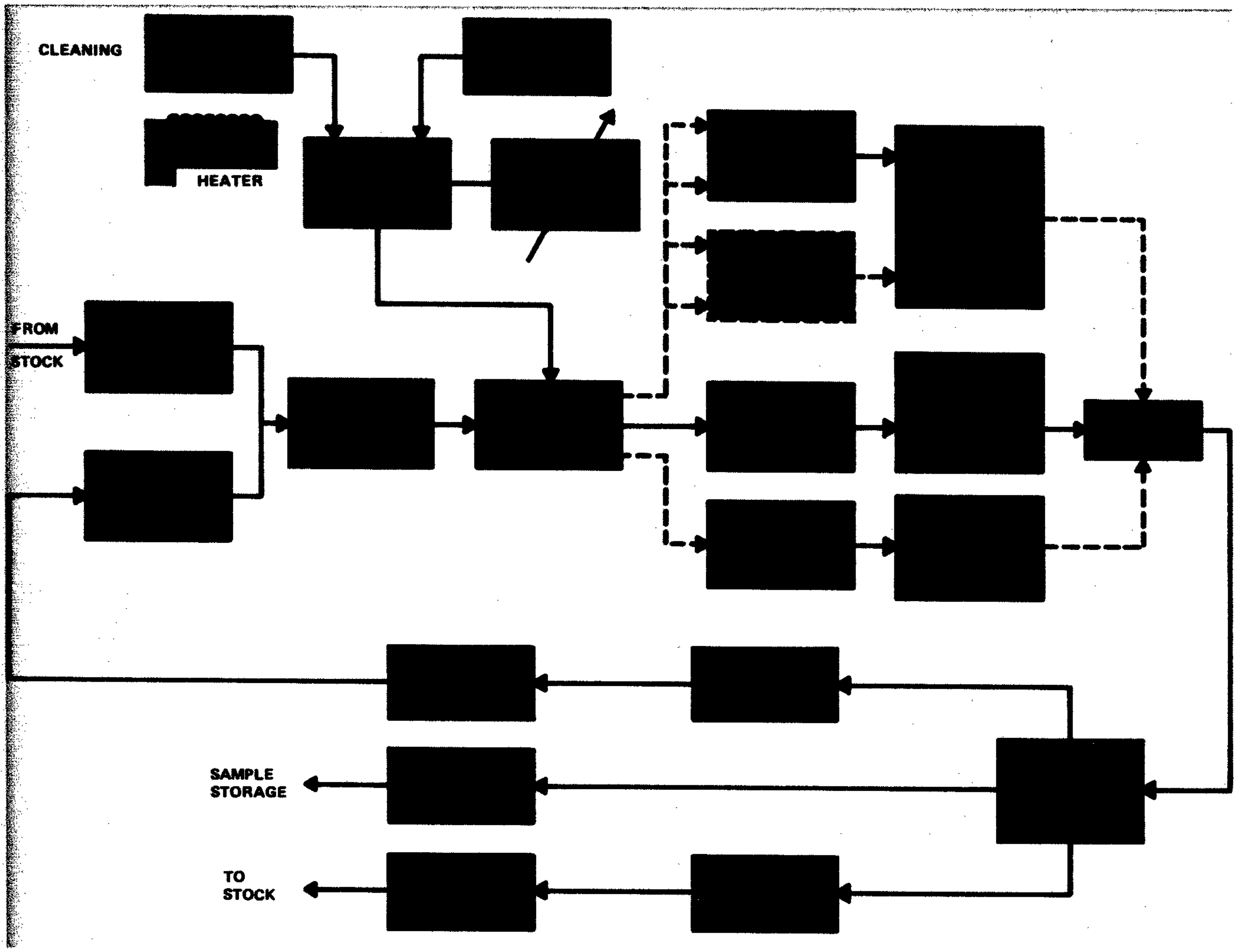


Figure 6

into the mold through a mixer which caused mixing to take place at the point of entry. Temperature blankets allowed the materials to be maintained at a high temperature to facilitate pouring by reducing the viscosity.

Structural Parts

Structural parts investigated included four areas as follows: shielded bobbins for high voltage transformers; thermoplastic and thermosetting plastics for coil supports; anchoring of windings within transformer coils; and C-core assembly techniques. The use of fine and ultrafine wires in high voltage windings increases the maximum voltage gradients in the encapsulation materials. Controlling the spacings of such wires which have high voltage differences is difficult; consequently, the use of electrostatic conductive shields (Figure 7) is employed in the construction of the bobbin. A typical high voltage bobbin will have a low potential or ground electrostatic shield on the outer surfaces with an insulated, but also conductive, shield on the inner surfaces where the high voltage winding is located. In this manner, location of the separate wires is not critical in controlling the voltage gradients being developed. Also, a modified bobbin was designed (Figure 8).

In high reliability transformer design, thermoplastic materials are rarely used because of their tendency to

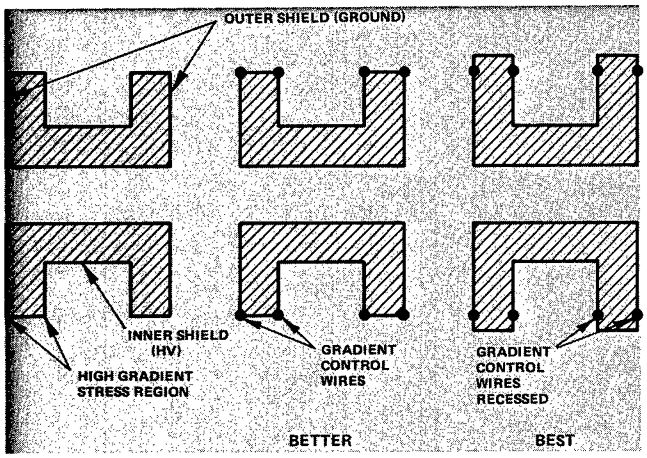


Figure 7

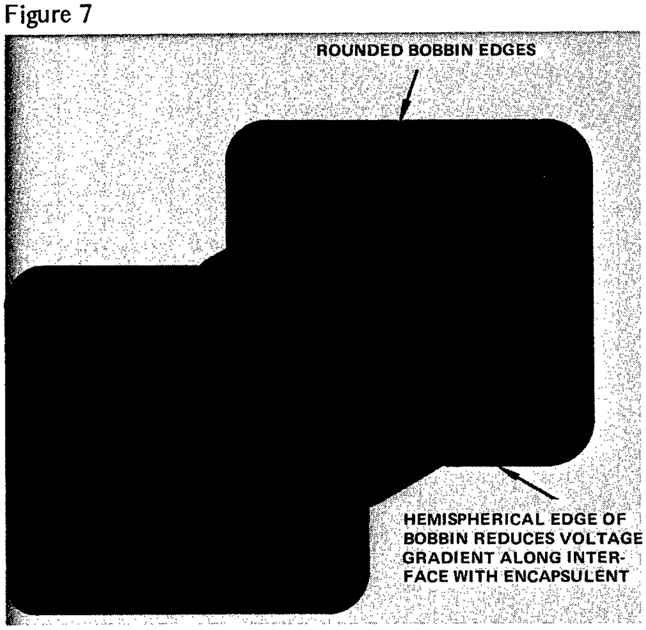


Figure 8

soften at the higher temperatures to which the component is subjected, either during testing or actual operation. Some of the newer high temperature thermoplastic materials such as Ryton (which has a softening point in excess of 525 F) were evaluated. Typical square bobbins of this material were obtained and windings made. Another requirement in the specification was that no softening of such thermoplastic material would occur when the terminals swaged in it would be soldered to. This was not found to be possible, as the softening could not be prevented by any acceptable soldering technique. The problem could be eliminated by a pulse type welding, but this seemed to add additional complications which overshadowed any advantages of using thermoplastic materials.

Non-Tape Alternatives

It is accepted practice to use small pieces of mylar tape to anchor windings at the end of each layer or at various stages during the winding operation. The presence of such tapes in a winding provides stress points in the encapsulation which can cause it to crack under thermal cycling, the possibility of entrapped air producing voids at critical parts in the winding, and a lack of adhesion of the encapsulation material to the tape itself. To provide an acceptable method of anchoring windings without using tape, several quick setting adhesive materials were investigated. These included hot-melt, ultraviolet curing, and anaerobic types. It was found that these provided an acceptable substitute for the tape once the operator became used to the technique.

Conventional banding operations of C-cores assembled into windings on bobbins or sticks (which have already been encapsulated) use a metal clip and a soldering operation to anchor the band. By means of welding an auxiliary pull tab on the band, a method of welding was developed which required no clip and no soldering. The pull tab and excess band lengths are then cut off after welding, resulting in a low profile of only twice the thickness of the banding strap material.

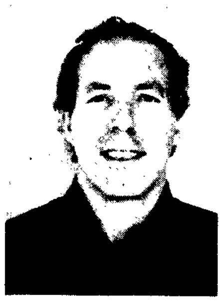
Implementation

Part of the implementation effort was the holding of a government/industry debriefing at Hughes-Culver City. The purpose of this meeting was to give to all attendees an overview of the information assembled during this 2-year MM&T program, to note the major findings, to point out possible breakthroughs in reliability improvement, and to review new technologies. It is hoped that this presentation encouraged those who attended to delve into the complete final report for the entire story. Hopefully appropriate portions of this technology will be implemented into other operations so that higher reliability, lower cost electromagnetic components for missile systems, space projects, and commercial applications would be forthcoming in the immediate future. If this is done effectively, a quantum jump in component reliability and cost reduction will be obtained which will benefit all concerned.

Possible Via Holograms

Testing Aspheric Lens Surfaces

WILLIAM A. FRIDAY is a Research Physicist for the U. S. Army Missile Command at Redstone Arsenal, Alabama, where he has been actively involved with the development of the technology base for high energy laser weapon systems. He has acquired experience in laser optics, laser beam control, and laser/materials interaction. He has worked for the Missile Command for the past 20 years, while earning B. S. and M. S. degrees in Physics from Mississippi State University and the University of Alabama in Huntsville.



The U.S. Army's manufacturing methods and technology effort has been instrumental in creating one of the world's most unique facilities for the use of American industry. The National Hologram Facility at Billerica, Massachusetts came into existence due to a mantech project funded by the U.S. Army Missile Command in its quest for a method for testing the surface accuracy of deep aspheric lenses. During the course of this project, which was carried out by Aerodyne Research, Inc., investigators turned to the computer to calculate and draw holograms that could be used as references for the testing of production lens surfaces. The achievements of the project will have impact for years to come in the field of design as the facility is made available to other U.S. Government contractors.

Simulation of not only the image but also the location of individual segments of the developing hologram plays a key role in making the system practical. The speed and location accuracy of mechanical devices during scanning were inadequate, so cathode ray tube imaging controlled by computer generated data points simulates the position of each succeeding segment in building the total holographic image.

Aspherics Pose Problem

The use of computers to calculate and draw holograms of objects or wavefronts that exist only as a concept in the mind of the designer is a technology that has been explored for many years by a number of researchers. Among the applications shown feasible are©

- Interferometric testing of deep aspheric lenses
- Recognition of spatial, spectral, or temporal patterns by computer optimized hologram filters
- Synthesis of three dimensional views of nonexistent objects for CAD/CAM
- Production of light, large, and efficient optical elements for all wavelength ranges
- Coordinate transformations on input images
- Duplication of optical hologram functions with better process control.

NOTE: This manufacturing technology project that was conducted by Aerodyne Research, Inc. was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is William A. Friday, (205) 876-8611.

Yet, despite the promise, computer generated holograms (CGH's) had not been applied widely outside the laboratory. The techniques to design the holograms were well developed, but writing them to sufficient accuracy proved very difficult.

In 1979, personnel at the U.S. Army Missile Command realized that holographic testing could be the key to testing the diamond turned aspheric optics the Army required. By diamond turning they could produce aspheric metal mirrors with almost arbitrary shapes; yet they had no way to verify the shape of the optics thus produced. Spheres and flats are tested routinely by optical interferometric comparison with reference spheres or flats, which can be produced to very high accuracy. But when the asphere deviates too dramatically from any reference sphere, the interferometric method breaks down—fringes become unresolvable and information is irretrievably lost. What was needed is a perfect reference asphere. But how would such an asphere be recognized even if it was produced?

The answer, known for many years, was to create by computer holography a light pattern (wavefront) appearing to come from the perfect reference asphere. Theory held that a hologram writer should write at least 40,000 points in each direction and have point location accuracy of at least one part in 40,000. No such writer existed at that time.

MICOM personnel set out to produce a suitable "holowriter" and make it available for all U.S. Government contracts. Accomplishing those goals would make writing adequate computer holograms easy and inexpensive.

In July, 1982 at Aerodyne Research, Inc. in Billerica, Mass., a practical holowriter constructed under MICOM direction was demonstrated. The holowriter is now in place at Aerodyne under the ownership of the Rome Air Development Center at Hanscom AFB, Bedford, Massachusetts. It is operated under contract at Aerodyne for the government and can be used in support of any contracts with the U.S. Government. The specifications achievable include

- Up to a 7 cm x 7 cm format
- Lines as small as 5 micrometers
- Absolute location of the center of each line to within 0.15 micrometers.

The 7 cm (70,000 micrometers) dimension at 5 micrometer resolution leads to 14,000 lines. The locational accuracy is one part in 4 x 10^5. Both of these numbers are comfortably greater than the minimum described earlier and much greater than prior art.

Basic Scheme

The basic scheme undertaken was to

- Use an ultra-low distortion CRT (greatly demagnified) to write a small, square portion (cell) of the hologram onto a photographic emulsion on an ultraflat photographic plate
- Translate the plate to write the next cell
- Measure the translation to an absolute accuracy of 0.1 micrometers interferometrically
- Write the next cell on the CRT face with position chosen to compensate for the unpredictable (to within a few microns) stopping position of the stage.

Of course, such a system had to be computer controlled. Achieving meaningful 0.2 micrometer accuracies required extremely careful engineering as well as the use of a temperature controlled room.

Figure 1 shows the overall system layout schematically. At lease a dozen factors converged to make improvements beyond the existing performance level very difficult and very expensive. A few of those factors follow:

(1) The special right-angle mirror required for the 2-D, orthogonal interferometry cannot be made much longer without itself introducing 0.1 micrometer errors;

(2) The writing time for a 10^6 x 10^6 hologram approached a full working day, and system stability for longer exposures was doubtful (to say nothing of latent image failure);

(3) Only one commercial photographic plate exceeded minimum requirements on sensitivity, resolution, and flatness even with the current (1979) design;

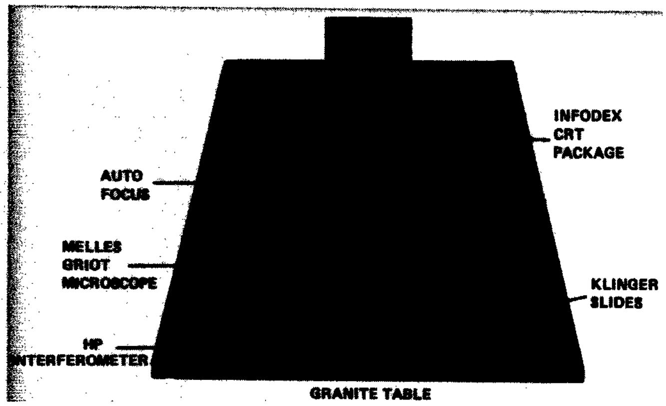


Figure 1

(4) The demagnification already was so great that it, not depth of focus, required the use of state-of-the-art controllers of lens-plate distance;

(5) Temperature gradients (beyond those already sensed and compensated for) as well as temperature drift limited mechanical measurement accuracies to no better than about 0.15 micrometers;

(6) Temperature variations within the room limited the CRT demagnification to roughly current values.

Hologram Encoding

Investigators chose to write binary holograms with continuous fringes and to achieve a 50% duty cycle for all fringes. The basic cell is shown in Figure 2. It is a square cell even though system asymmetries give it 2000 horizontal but only 800 vertical pixels. As will be seen, the fringes will be predominantly vertical, so phase accuracy is controlled by the 2000 pixels while the 800 pixels simply allow for the slow bending of the fringes. The minimum fringe to be written is 4 micrometers, but its center can be located within 0.15 micrometer.

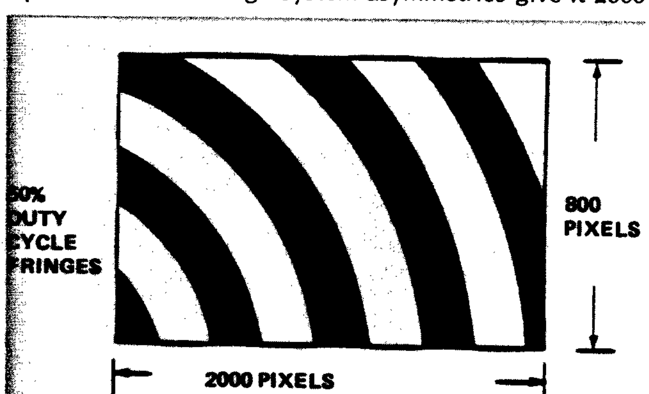


Figure 2

To calculate the exact fringe values at $10^6 \times 10^6$ points even at the incredible rate of one microsecond per point would have taken months. Obviously, some shortcuts had to be taken. To help find fringe centers, a priori knowledge was utilized that the fringes are:

- Largely vertical
- Nonintersecting
- Continuous.

With the fringe centers investigators could get local fringe spacing and hence know the fringe width necessary to give 50% duty cycle. With their a priori knowledge that the fringes were largely vertical, they were safe in not calculating fringe centers at each possible vertical position. The calculation of fringe centers used the Secant method, with the starting guess made on the assumption that the next fringe spacing equals the previous one.

Quibbles

Two objections to computer holographic testing of aspheres can be made:

(1) The wavefront produced is accurate only modulo λ (the wavelength for which the hologram was designed). This, of course, precludes multiwavelength testing. In addition, this creates optical path differences which preclude testing with sources of too limited temporal coherence.

(2) The hologram design is based on optical path differences which are calculated by computer ray tracing of the interferometer system. Unless the system (particularly its lenses) is known to great accuracy, users can easily produce the wrong wavefront by designing the hologram for an interferometer not available. There is no way to avoid this problem in any testing method (holographic or nonholographic).

DESIGN CONSIDERATIONS

Designing the holowriter required the careful selection of components and equally careful attention to the environment in which those components had to function.

Temperature of Room

The primary effect of changing room temperature is to change the physical dimensions of all the metal components, bases, and supports. Listed below are some of the ways those dimension changes can be expected to cause problems:

- The demagnification factor may vary because the object distance and image distance (relative to the principal planes of the microscope) may change as the basic structure shrinks or expands.

- The lateral position of the optical axis of the microscope may change relative to the CRT and/or relative to the stage.

- The separation between the interferometer and the mirror it is measuring may be due partially to mirror motion and partially to temperature induced changes in system (e.g., baseplate) dimensions.

There are only four ways to combat this problem: (1) design in temperature compensation, (2) minimize temperature change, (3) use nonexpanding materials, and (4) measure temperature and correct for it.

Compensation means using the known expansion coefficients of different materials to design counteracting temperature effects. This was used, for instance, in keeping the microscope axis properly aligned with the support system.

Temperature "constancy" was achieved by building the system in a temperature controlled room. Most heat sources (except the CRT) also were kept outside that room. With temperature considerations, the questions are: how stable is the temperature over the anticipated writing times and how big are the temperature gradients?

Low expansion materials (e.g., special ceramics) were seriously considered for the baseplate and other major structural components; however, cost and inconvenience ruled them out.

Measure-and-compensate methods are used to correct the interferometer readings for the effects of temperature gradients.

When effects of all the tradeoffs and compensations are combined the conclusion is reached that the lateral accuracy depends on the total temperature excursion during the total writing time. Time enters in as a further drift problem. Thus, there can be a drift in the reference to which the room temperature is compared. This is not believed to be significant during any one working day.

In a more expensive system of the future, significant improvements could be obtained by using

- A temperature controller with greater stability

- Low expansion ceramics wherever possible. This could lead to roughly a factor of two improvement.

Stage Motion

As the stage micrometers are driven, the stage itself undergoes periodic up and down motion from the gear drive. This motion is certified by the manufacturer to be ± 1 micrometer. The primary effect is not on focus (our depth of focus is around 25 micrometers) but on the demagnification ratio.

When attempting to drive the stage to a new position, a location is arrived at that differs from the target position by unpredictable errors. These errors are the settling errors certified to be roughly 10 micrometers. The approach to dealing with these errors is to write the CRT image laterally displaced from the center. The demagnified image is then automatically centered.

Photographic Plate Choice

The photographic plate had to be extremely flat to achieve good resolution because of the previously noted demagnification effect. Kodak offers the flattest available photographic plates (Microflat©).

In photographic emulsions big grains are used to gain high speed. Because high resolution is required, low speed must be expected. Lower speed means longer exposures. Longer exposures mean less resolution. Clearly, there is a narrow "window" in the set of all emulsions which satisfies a mutually consistent, useful tradeoff between speed and resolution. Of the few potentially interesting emulsions, only one was available on

Microflat plate. It was concluded that this was the only commercially available photographic plate suitable for use with this hologram writer.

CRT Choice

The CRT choice was dominated by considerations of speed and distortion. To avoid writing the hologram a point at a time, investigators chose to write it a square cell at a time. The speed improvement factor in so doing is the number of points in the cell. The ultimate speed, of course, would come from writing the whole hologram at once. For the number of points and for the positional accuracy required, this ultimate CRT does not exist. The question then is how large a cell (in terms of number of resolvable elements) can be written to required accuracy. The original objective was to write fringes to $\lambda/100$ accuracy. With a fringe period of 10 micrometers this requires 0.1 micrometer on the hologram. On the CRT it requires $\rho/50$ accuracy across the cell, where p is the width of a single point. That is, the cell needs to be confined to that region of the CRT giving less than 2% distortion. For a bad CRT the cell may be very small. For the best CRT, it may be very large. For the good and affordable CRT the Infodex PD1200M34 with a 12 cm diameter RCA C82200 ESI tube was chosen. The usable area was 5 cm x 5 cm for this project.

The image must be "on" long enough to expose the emulsion. It must be bright enough so that retrace is not required to achieve the desired exposure level. The phosphor decay time should be less than the time needed to step the stage and let it settle to within 0.1 micrometer. For this system that time is 0.17 seconds. The decay time for the RCA tube phosphor is 0.001 seconds.

The chief obstacle to better CRT performance (bigger cells) is cost. The next best CRT was roughly $5,000 more than the one bought. In a program in which cost was a prime consideration, this was not a difficult option.

Mirror Design

The right angle mirror attached to the stage to allow stage x-y position monitoring must be locally flat to allow the interferometer to function. In addition, it must be accurately 90 degrees in order to not couple x and y measurements. If it were exactly 90 degrees, the mirror could be aligned at $x=x_0$ and mirror alignment could be adjusted so that the x indication is constant to better than 0.1 micrometer regardless of y. The test is to move to a much different value of x and scan y there. It should again lead to "constant" x.

It follows that investigators cannot expect to avoid correcting x according to y—i.e., calibrating the mirror and storing a simple correction factor for use by the computer.

Vibration

In a system designed to approach 0.1 micrometer positional accuracy, normal vibrations would be catastrophic. Four precautions were taken to minimize vibration. First, an air-suspended table was used to isolate the system from normal slow vibrations (people walking, machinery operating, earth settling, etc.). Second, a granite table was used to damp fast vibrations. Third, only heavy, solid components were used. Fourth, holograms were written only after disturbances from stage motion and disturbances from human operators had time to dampen out.

Air Currents

The temperature controlled room continually circulates air. This should maintain the desired temporal and spatial uniformity, but it can also cause sufficient turbulence to cause misdirection of the writing beam. Turbulence spoiling shields were built to remove this problem.

Interferometer

The interferometer was one of the easiest choices. What was sought was

- Resolution of 0.1 micrometer or better
- Reading speed sufficient to verify damping of stage motion relative to stage settling time.

The standard of the industry is the Hewlett-Packard interferometer chosen. It is more than adequate on both counts.

Radio Frequency Interference

Radio frequency interference (RFI) was anticipated that would present a problem for delicate display circuitry and so investigators tried to shield the environmentally

controlled room against it. It turned out that RFI also affected the controlling PDP 11/23 computer. After much effort, this and a line surge problem caused by the room environmental controls were brought under control.

Information Flow

Two primary tasks were needed to be accomplished by computer:

- Calculation of the hologram (a nontrivial task in that the writing beam must be fed information to 0.1 micrometer accuracy over an 8 cm diameter hologram for a total of about 5 x 10^6 bits)

- Control of the writing (move the stage, sense stage position, write the cell, decide next cell position, obtain cell data, etc.).

In principle, one computer could do both tasks. In practice, this proved far too expensive.

To operate the holowriter at its design speed while making fringe calculations on the fly, Aerodyne's PRIME computer would have had to be devoted full time to the task (all other users banned for the entire writing time). The financial burden to the program of this operation would have been immense. Instead, it was chosen to split the tasks between two computers by providing a dedicated PDP 11/23 to control the holowriter. The primary cost (in time, inventiveness, and dollars) of this approach was that an interface between the computers had to be designed and built and a 100-foot special cable had to be designed and installed to connect the computers. A simplified task division is shown in Figure 3.

SYSTEM DESCRIPTION

Having described the system philosophy, the system components, and the system design parameters, the system is now described as a whole. In a sense, the system was designed once the components were selected. Unfortunately, most of the hard work went into assembly and integration.

System Appearance

The CRT, mount optics, stepping motors, and interferometer were located on an air suspended granite

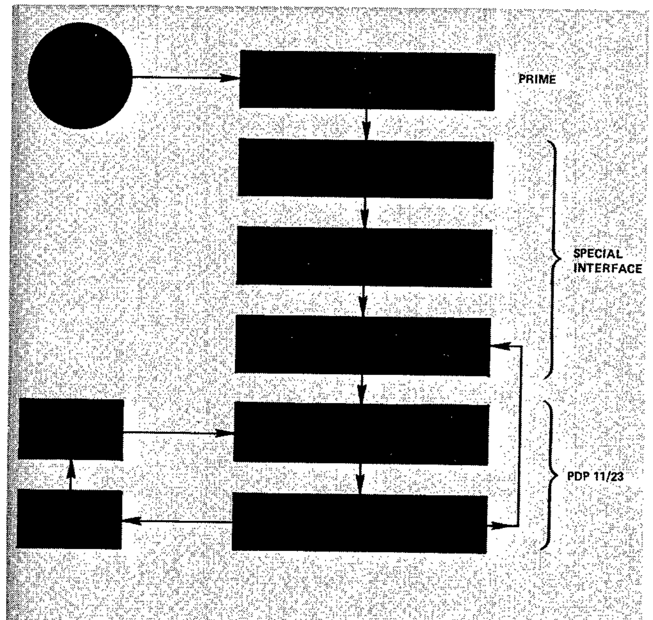


Figure 3

table in the environmentally controlled room. The room environment is set, controlled, and recorded, and two entries to the room are locked during hologram writing. The room had to have all light leaks plugged and all control lights covered because the plate is panchromatic and is exposed for a multi-hour period. All manual manipulations after the plate is removed from the box are done in darkness using an infrared viewer. Outside the second door of the primary double chambered entry way is the PDP 11/23 and associated I/O equipment. The operator controls all operations from there. Down the hall is the PRIME computer used for the fringe calculations and the interface based on the PRIME/RAMTEC interface which was already designed for rapid data transfer from the PRIME.

Alignment, Magnification, and Focus

Plates are inserted in the dark (as noted above) and kinematically located within the plate holder. The location of the first fringe is selected by the starting point on the micrometers on the stage motion transducers. The magnification can be "trimmed" electronically. By exposing square cells (which ought to abut perfectly) on a test plate while changing magnification between

cell exposures, agreement can be achieved between the cell size on the plate and the interferometrically controlled stage motion. Thus, the scale of the cell can be accurate to interferometric accuracy. Focus can be obtained through direct observation of backscatter through the pellicle beam splitter. It has proved satisfactory in practice to

- Align the plate holder apparatus once optically so that no focus change occurs over the whole plate
- Measure the air gauge gap indicator reading
- Use the air gauge to reset the focus for new plates (the microscope must be elevated and reset in the dark to insert a new plate).

Operational Notes

The center (low distortion) part of the high-quality television tube (Infodex) is used to write a 5-cm square cell. This is demagnified by a factor of 250 onto a Kodak Microflat© plate bearing a holographic emulsion. The resulting 200 micrometer square can contain up to 40 lines (20 full fringes). After the first square is recorded, the system is stepped to the next nominal position 200 micrometers away. Of course, the stage will not settle to exactly where it should. A two-axis interferometer reads the actual stage position to within 0.1 micrometer.

Readjusting the stage position is too slow, so the next cell is drawn so displaced on the TV face that it is imaged perfectly abutting the previous cell. The TV cell image, being nonmechanical, can be adjusted in position much faster than the mechanical stage. Speed is important, because it takes 122,500 of these cells to form a full 7 x 7 cm hologram. The holowriter completes the task in about 10 hours.

Each hologram is annotated automatically and is given precisely placed fiducial marks to allow accurate positioning.

Because there are severe problems with stability, vibration, temperature drift, and humidity changes, the holowriter is designed to compensate for these effects and is placed on an air suspended granite table in an environmentally controlled room.

Final System Specifications

Table 1 shows final system performance levels.

Parameter	Value
Hologram Size	7 cm x 7 cm
Fringe Size (minimum)	5 micrometers
Absolute Location Accuracy	0.15 micrometer
Writing Time (full format)	12.5 hours

Time Budget for One Cell

Table 2 shows the time required for the various operations.

Operation	Time (milliseconds)
Step	170
Expose (2 traces)	100
Total	270

Sample Rulings

Figure 4 shows a magnified area covering several cells. This illustrates the accuracy and quality now achievable.

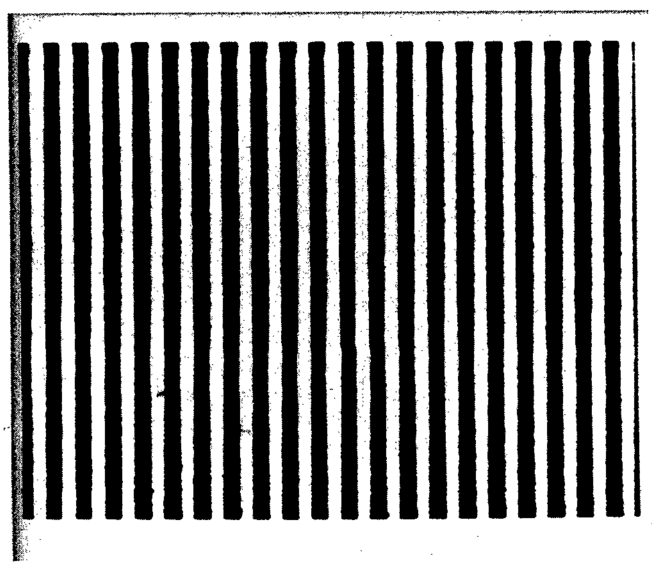


Figure 4

USER NOTES

Hologram Design

The user must supply

- Best fit polynomial coefficients for the phase function (measured in wavelengths with the maximum radius, ρ, equal to 1).

Higher orders are easy to handle but normally unnecessary to achieve desired accuracy levels. To achieve $\gamma/20$ accuracy, equations should differ from the computer calculated patterns by at most 5%. The user then supplies

- The tilt angle
- The maximum radius (corresponding to $\rho = 1$)
- The wavelength.

Sample Run Made

A simple case was run to show the workings of the program. None of these parameters were realistic, but were intended to give an interesting output plot. The system says that the maximum number of cells (along the hologram diameter) is 10. It also says that there are 60 fringes across the hologram. Figure 5 shows a plotter version of the magnified hologram. Each of the small rectangular cells that makes up a fringe should be black (and it is on an actual hologram). Points within these cells all have the same horizontal displacement, because investigators elected not to calculate every vertical line but, instead, to calculate only every Nth/ line. In this case N = 10. This gives a factor of N increase in the calculation speed and need not cause any measurable errors. The top and bottom rows are barely intersected by a $\rho = 1$ circle, so the system extrapolates straight fringes outside $\rho = 1$. The artifacts at cell "seams" stem from the fact that the plotter is not as accurate as the holowriter. Note the 50% duty cycle fringes across the whole hologram. This is one of the unique features of the Aerodyne computer design software, which leads to a uniform diffraction efficiency across the hologram.

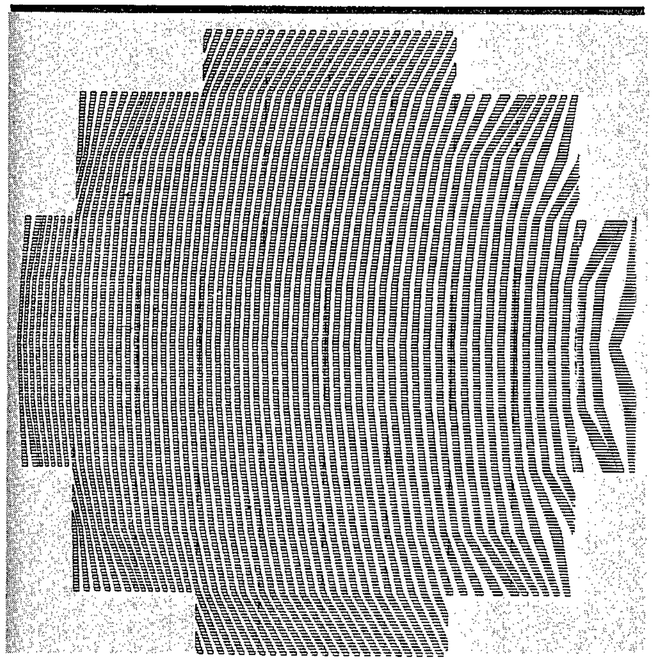


Figure 5

Calculating the Hologram

The PDP 11/23 computer that operates the system must provide precisely 2.06×10^{11} bits of information to the holowriter. Calculating and handling this amount of data at roughly megahertz rates is a formidable task. The National Hologram Facility has written special hologram design computer programs for testing aspheres and for general-purpose Brown-Lohmann holograms.

Future Uses

The CGH equipment is now available to many users at reasonable cost (charges cover only labor, materials, computer time, and maintenance). Wavefronts produced from CGH's are easily copied optically to produce thick, efficient wide splitting angle holograms. CGHs can be copied onto photoresist for metalization or other treatment, leading to long wavelength (e.g. 10.6 micrometer) holograms. The possibilities are now limited only by user ingenuity.

New System Versatile in Production

Modular Device Tests Electro-Optic Components

by

William A. Friday
U. S. Army Missile Command

(See "Testing Aspheric Lens Surfaces"—p. 18)

Testing of electro-optical components has been advanced to a much higher state of sophistication by the U.S. Army Missile Command as a result of two companion MM&T projects that the command has sponsored. This article discusses the problems inherent in optical system design and presents the methods developed during the project to surmount these difficulties. The project developed a high-speed automated lens tester which measures focal length, modulation transfer function, defect location, and surface scatter. The effort was companion to a manufacturing technology project described in another article in this issue in which MICOM sponsored development of a computer generated hologram writer to test deep aspherical lens surfaces.

Under the MICOM MM&T contract, a modular device was designed and built by Science Applications, Inc., for optical components and systems. The system allows testing of a wide range of diameters—afocal or focusing, transmissive or reflective elements—and complete systems of any complexity with appropriate tailoring of input and output wave fronts. The system is designed for a production environment to provide high sampling rates with data collection and analysis complete in a few minutes per element.

Overspecification A Problem?

The design of an optical system requires more than an understanding of the theories of geometric and physical optics. There is a technology of component and subsystems production that must be dealt with. Otherwise, the resultant optical system may well be inefficient, too expensive, low performance, or all three. The U.S. Army,

NOTE: This manufacturing technology project that was conducted by Science Applications, Inc. was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is William A. Friday, (205) 876-8611.

in its absolute need for high performance and reliablity, felt that it might be overspecifying and perhaps incorrectly testing electro-optical devices. If so, it might well prove to be spending more money than required. Additionally, it might be forcing vendors to supply designs that were weight or size inefficient. Furthermore, it becomes a matter of suspicion that the optics, being the very front end of a seeker missile, should amost always be designed first, not last.

Once an optical system is decided upon, the spatial requirements and the component interrelationships are not very flexible. Unfortunately, it is not at all uncommon for project developments to let the optics take a back seat. Perhaps this is because optics is so mature a field of science that it is taken for granted that it will not present the problems expected of aerodynamics and microelectronics. However, it should be pointed out that it is far simpler to modify a breadboard circuit to "tweak up" its temporal frequency response than it is to improve the spatial frequency performance of a lens or mirror.

Parameter Specification

One would hope that optical component and assembly specifications would be based on a clearcut understanding of what happens to overall system performance if some parameter is changed. In the case of an optically guided missile it would be hoped that the influence of increased scattering, for example, on the acquisition and accuracy of the seeker would be known. In fact, the investigations of this study showed it not so. As this circumstance became clearer during the program investigations, an avenue was sought by which such information might be obtained. In effect, it was found that the area of investigation needed to be extended from the area of concern initially proposed.

With this objective in mind, discussions were undertaken with the U.S. Army Missile Command's Guidance and Control Directorate. In particular, the G&C facility for hardware-in-the-loop captive sensor simulation of homing missile flights was visited. This facility is designed for low cost statistical analysis of miss distances for laser spot seeking missiles. Figure 1 shows the basic arrangement by which a seeker head is strapped into a multiaxis motor driven gimbal and a laser spot is rear projected onto a screen. Digital and analog computers are used to calculate aerodynamic effects and to cause laser spot displacement and gimbal motion in simulation of the missile's closure on a target. At the end of a run, the miss distance is output. Statistically significant data can be com-

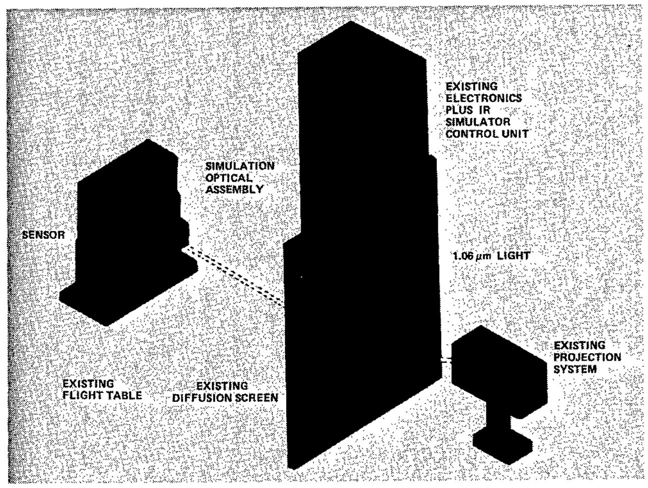


Figure 1

piled since large numbers of runs for various acquisition ranges and angles can be made at low cost.

It was suggested to the facility director that an optical seeker assembly be made available for modification to its optical components. These modifications would be made in a controlled manner and categorized by the proposed automatic testing facility. In this way, a large amount of system performance data could be compiled by multiple runs of the sensor after each modification. The resultant data would be unprecedented and would, perhaps for the first time, lead to seeker component specification based on something other than educated guesswork.

OTF Gives Best Measurement

The contractor has examined production testing as it relates to tactical electrooptic homing missiles and suggests that the optical transfer function and scattering measurement concepts are basically both sound and applicable. The U.S. Navy at China Lake, California, is active in investigation of scattering phenomena and measurement.

The contractor concluded that simple adaptation of the many scattering measurement optics would be adequate for seeker and designator optics. A similar situation exists in optical transfer function (OTF) measurement except for the fact that the techniques and explanations of OTF, derived from electrical engineering practices, are only a partial adaptation. Everyone seems to understand the "big picture" or idea of OTF at the component and assembly levels, but few in the optics community are able to address its details on a practical level. Accordingly, the con-

tractor's work was concentrated on this area. This included efforts to interact with project offices and to communicate their activities with the optical community at large. The optics community is making some progress toward adopting the pragmatism of Project Offices by organizing a group (which includes the contractor) to arrive at specification via consensus standards.

Two categories of testing have been delineated by practical applications over the years. One category is particularly suited to in-process measurement while a single component is under fabrication. This category uses interferometric techniques to determine surface figure. However, once a component has been completed, it is best tested with regard to result system performance. This generally involves measurement of spectral efficiencies, scattering coefficients, and spatial resolution.

Traditionally, the spatial resolution has been given in terms of limiting resolution. However, it was recognized that two systems could have the same limiting resolution yet have very different system performances. This results because limiting resolution implies specification of performance at a single spatial frequency. In practice, complex optical arrangements can include aperture shapes, obscurations, and detection techniques that rely on spatial frequencies less than the limiting resolution. It is possible for an optical assembly with better limiting resolutions than another to actually give poorer system results if lower frequency components are important, as often is the case.

The most meaningful attempt to improve the appropriateness of component performance in an assembly grew out of linear systems theory and Fourier analyses. This is the approach most meaningful to evaluation of missile seeker optics. This approach is generally termed optical transfer function (OTF) analysis (Figure 2).

Transfer Function Theory Practical

Despite rapid growth in the field of optics during the late 1960s and the 1970s there is still a widespread acceptance of the criterion known as resolution. For many years the classical method of assessing image quality has depended upon the measurement of the limiting resolution of the particular system under evaluation or of the system and film combination. This type of test can have the advantage of including the detector, as for instance in the photographic resolution testing of a lens to be used for photography or the visual testing (by observing adjacent stars) of an astronomical telescope.

The tests are tedious to perform and must be carefully controlled to be meaningful. Therefore, the information

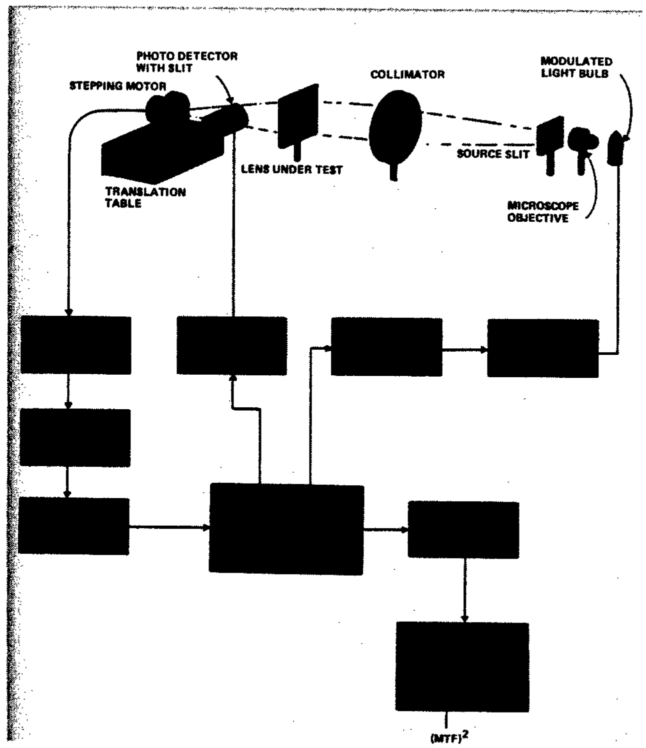


Figure 2

that they provide is of little use for anything other than determining the limiting resolution of the system. Even so, the measurement must be extremely questionable, particularly when the image is received on a screen or viewed in a microscope. In these cases the resolution may be limited by the coarseness of the screen or the available magnification of the microscope.

The tests themselves produce results that are of little use to the optical designer as a quantitative guide to modifying his design. In addition, the type of test object, usually a three-bar square-wave target, bears little correlation to an actual scene since it is neither a typical shape nor comprises a single frequency.

Despite the problems associated with resolution, only a few of which have been listed above, it remains obstinately in use today as a basis for manufacturing and evaluating optical systems. Only in the field of optical design has a more advanced terminology become universally accepted.

One of the biggest problems has arisen in the last decade due to the introduction of a wide range of new electronic imaging systems, which has considerably magnified the problem of specifying and designing optical systems for use with them. It was determined many years

ago, principally in the television field, that lenses with the highest resolution were not necessarily the best lenses for use with image orthicon tubes. As far back as 1948, the real key to specifying lenses and detectors in similar terms was discovered.

The establishment of a transfer function theory in optics, similar to frequency response in electrical circuits, provided the relationship that was required. For our purposes it is convenient to regard the transfer function merely as the relationship between the input and the output of an optical system. The theory utilized here was developed by many independent workers over the years and is based on a combination of electrical communication theory and optical diffraction theory. Because of the versatility and completeness of Transfer Function Theory, it has become a standard practice today to specify and design systems in these terms. This has demanded an understanding of the principles from a wide variety of disciplines—optical, mechanical, electronic, and chemical engineers for example.

Basic Imagery Principles

The quality of the image formed by an optical system is determined by three factors:

- Aberration in the optical system
- The wave nature of light (causing diffraction effects)
- Inaccuracies incurred due to manufacturing processes.

When the design is such that the aberration can be neglected (such as an f/2 lens stopped down to f/16) and errors of manufacturing are so small that they have no effect on the performance, then the quality of the image system is said to be "diffraction-limited."

Consider a lens system that forms an image of an incoherently illuminated narrow slit. In the ideal case, the distribution of light in the image would be an exact replica of that in the object. This can, of course, never be realized because of the finite wavelength of light.

If there is aberration present in the optical system, and in particular if the aberration is asymmetrical (as, for example, in a lens afflicted with coma), then the image is extremely complex. The intensity distribution in the image of a narrow, incoherently illuminated slit is known as the "line spread function" of the optical system forming the image. If the slit is replaced by a pinhole the corresponding function is referred to as the "point of spread function."

For the purpose of considering image formation, each point in the object can be thought of as a source, giving rise to a point spread function from different points in the object. This approach gives a good indication of the process of image formation but is not, however, the best approach toward designing and assessing optical systems.

A more suitable test object can be obtained by utilizing a sinusoidal intensity distribution. The image of a sinusoidal target always has a distribution that itself is sinusoidal. Behind this fact lies the whole basis for transfer function theory.

Consider a sinusoidal type target being used as a test object. In the ideal case, the object and image are identical, but since this, in reality, is never the case, the best we can achieve would be a diffraction limited image. The effect of diffraction is to reduce the amplitude. If aberration is present, in addition, the amplitude would be further reduced in the presence of asymmetrical aberration; the amplitude reduction is also accompanied by a phase change. If N is the distance between successive peaks of the target (in millimeters), the spatial frequency of the target is defined as 1/N-R cycles/mm. This is analogous to the familiar lines/mm term used for resolution charts. In the case of afocal systems, the units more frequently used are cycles/milliradian.

Modulation Transfer Function

An important property of the sinusoidal intensity distribution that we will utilize is the modulation. It will be noted that the mean luminance is taken high enough to bias the function such that the luminance is always positive. The modulation is often referred to as the contrast, but since the definition of contrast is not always the same, particularly in the photographic field, the term modulation will be adhered to.

Next consider a series of sinusoidal targets of varying spatial frequency but of constant amplitude. Later, as test objects, their images will be of reduced amplitude and the corresponding modulation can be calculated for each spatial frequency. If we define the modulation at zero cycles to be 1.0, a graph can be plotted of modulation against spatial frequency (Figure 3). This represents the variation of modulation with spatial frequency and displays what commonly is known as a "Modulation Transfer Function" curve, often referred to as an MTF curve.

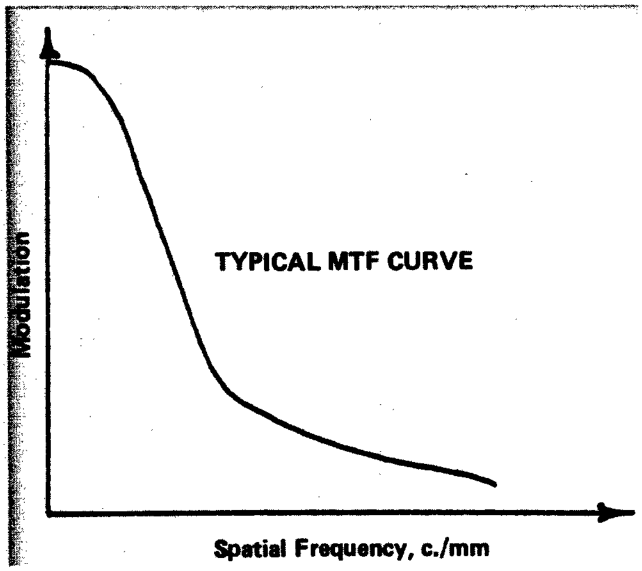


Figure 3

In the case of a lens possessing asymmetrical aberration or badly centered elements, the effect of the lens system is to cause not only a reduction in modulation but, as previously mentioned, this will be accompanied by a phase change. This phase change is dependent upon spatial frequency and contributes to what is known as the "Phase Transfer Function (PTF)." It is conveniently represented by the type of graph shown in Figure 4. Note, particularly, that this is a spatial phase shift and can only occur where the point image is asymmetric. Thus, in a centered optical system, spatial phase shifts occur only "off-axis" and for tangentially oriented lines. Radial lines will have no phase shift.

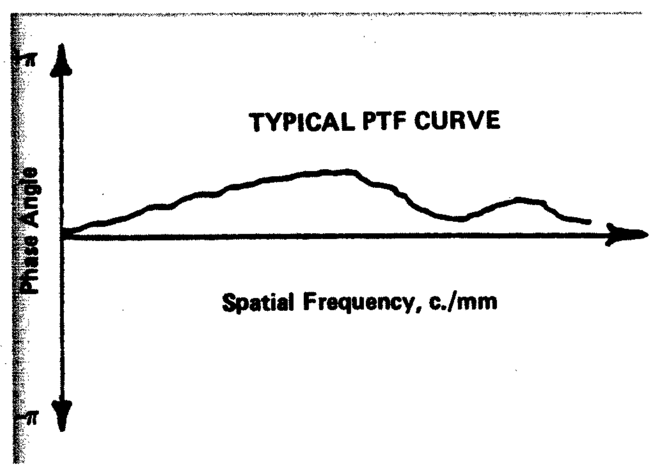


Figure 4

An interesting effect can be observed when defocusing a symmetrical lens, when phase shifts of 180 degrees can occur. This is consistent with visual observations when compared with the more common experience of observing the alternate bright and dark centers to the on-axis diffraction pattern as the system is traversed through focus.

Measurements of Modulation Transfer Function and the Phase Transfer Function combine to give what is known as the "Optical Transfer Function (OTF)" for the system under test. The OTF of a system can be obtained from the Fourier transform of the line spread function of the system under test.

Mainframe Configuration

All optical and electronic support hardware directly related to processing and control are located on the optical mainframe. The controller terminal including the data acquisition system, data storage, CRT keyboard assembly, and the line printer are remote from the optics mainframe. This division of the total assembly provides the user at the controller console with all necessary controls for system operation. All possible test functions are designed with automation in mind, therefore, the need for operator access to the optics mainframe is minimized.

The principal difference between the mainframe and a standard optical table is its three dimensional nature. For all practical purposes, a table is only two dimensional and an optical bench is only one dimensional (mirror adjustments excepted). Furthermore, standard tables and benches are not portable. The chosen mainframe is designed to be movable.

The mainframe concept is predicated on the recognition that repeated, detailed testing will be done on replicated components, assemblies, and systems. All tests, however, require standard elements. These are generally thought of as standard sources and detectors. In addition, there is an implicit wavefront standardization. Optical engineers commonly utilize either or both of two standard wavefronts: the plane wave and the spherical wave. The mainframe incorporates a collimator for converting a spherical wave into a plane wave.

In looking at the optics mainframe, a light path may be traced from the source assembly through a collimator. The path then proceeds to the test object. For the case of a transmission test system, the light path is traced to a detector assembly located behind the test system.

The design incorporates an off-axis parabolic reflector to provide greater flexibility in the choice of spectral range from 0.4 to about 14 millimicrons. More precisely, the

reflectivity is relatively flat over this range and effects of chromatic aberrations are eliminated.

Measured Optical System Parameters

The test facility is designed to perform specific optical tests at the system or component level. The measured parameters include:

- Focal length
- Optical transfer function
- Large area scatter
- Local scatter
- Spectral characteristics.

Depending upon the device being tested, a selection of tests is developed which adequately characterizes the system under its normal range of operating conditions.

After an optical component is mounted on the test jig, the focal length can be estimated to within 5-10 percent; testing will be centered about this estimate and the peak value then chosen.

Because the location of the principal plane may not be known, the focal length measurement is performed in such a way as to be independent of alignment reference to the principal plane. A translator on which the detector is mounted is moved perpendicular to the optical axis until the focal point is found. From this measurement, the focal length is computed. Focal lengths of both single components and complete systems can be found in this way.

The system layout for OTF testing is shown in Figure 5. A folding mirror reflects the source radiation onto an off-axis parabolic mirror for collimation. A four-inch-diameter beam is then directed onto the test component. The test assembly consists of a test block for mounting the optical component to be tested and two translators. The translators are used to position a pyroelectric detector for focusing and off-axis measurements. The entire test block is mounted on a rotor for scanning.

A diagram of the OTF process is given in Figure 6. The detector signal is first locked in by the automatic gain adjustment. The slit temperature is recorded from a temperature sensor located on the slit mount. The step size of the scan rotator is determined based on the focal length of the test component. A scan is made of the line spread function with detector readings synchronized to a 5Hz chopper signal. Readings are made and data sampled at the Nyquist rate for a 0.5Hz signal bandwidth corresponding to 100 lines/mm. The data is stored and then scaled spatially as necessary based on the focal length of the test component. The OTF is then determined from the line spread function data using the hardware processor. The results are processed for display and storage.

The system layout for scatter measurements is shown in Figure 7. The component to be tested is mounted on the test block and rotated into position using the scan

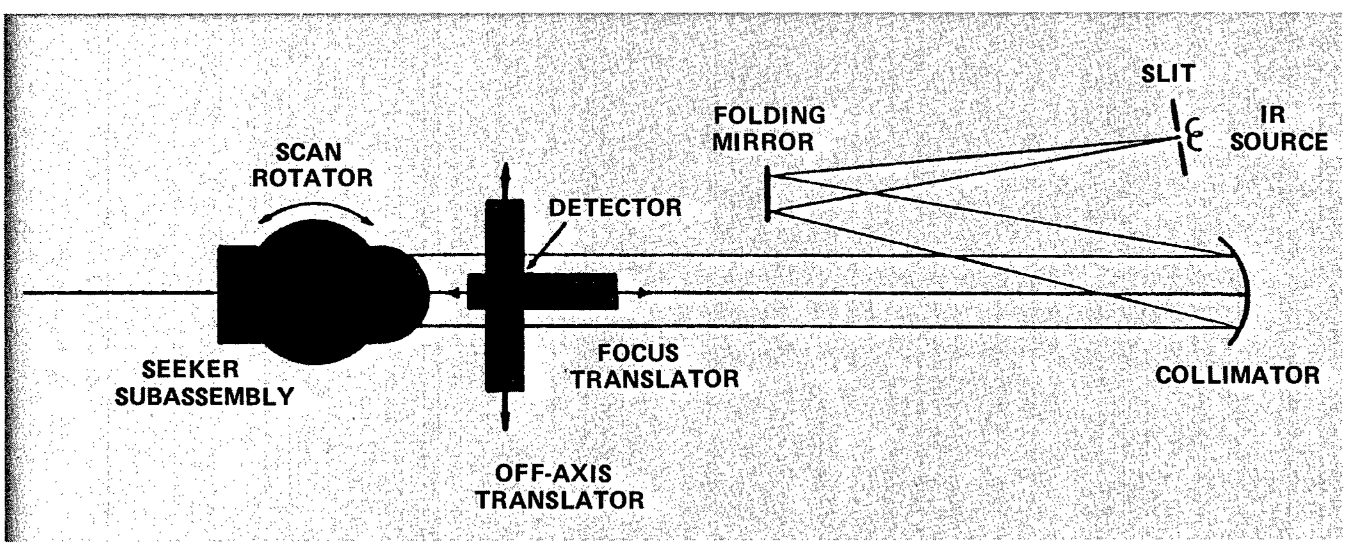


Figure 5

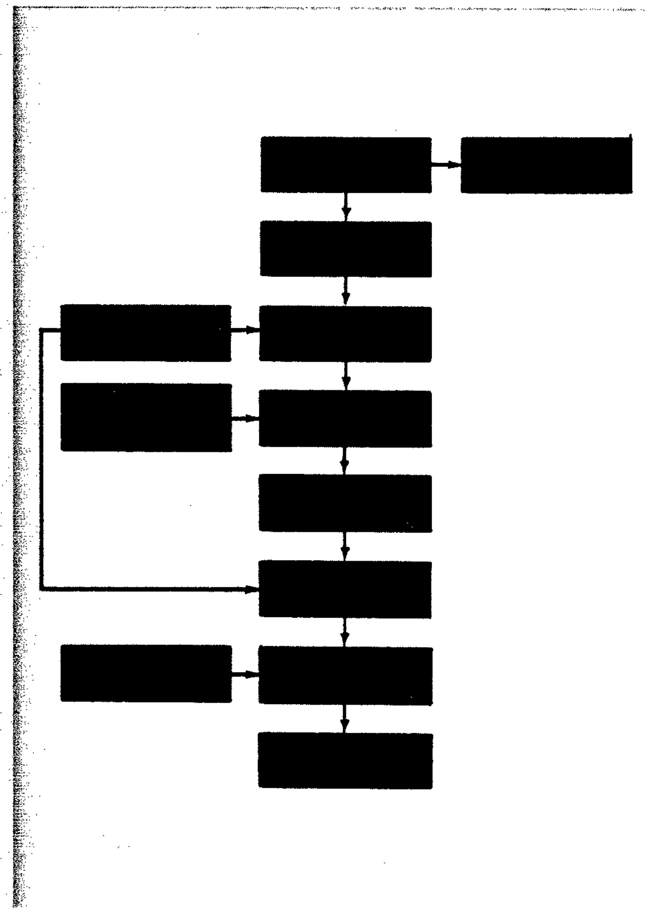


Figure 6

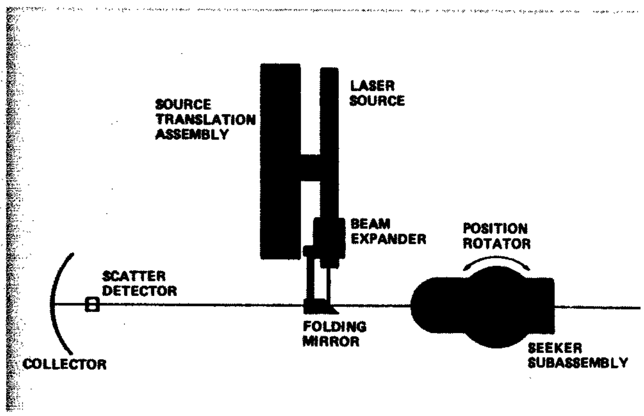


Figure 7

rotator. A laser source consisting of a helium-neon laser and beam expander is used to generate a laser beam approximately 1.6 cm in diameter. A folding mirror directs the beam onto the test component. The source assembly is mounted on two translators which are used to position the beam sequentially in a raster pattern over the entire area to be tested. An 8-inch collector mirror focuses the scattered radiation onto a silicon detector.

A diagram of the scatter measurement process is shown in Figure 8. The test assembly is positioned under computer control. The laser source is sequentially positioned

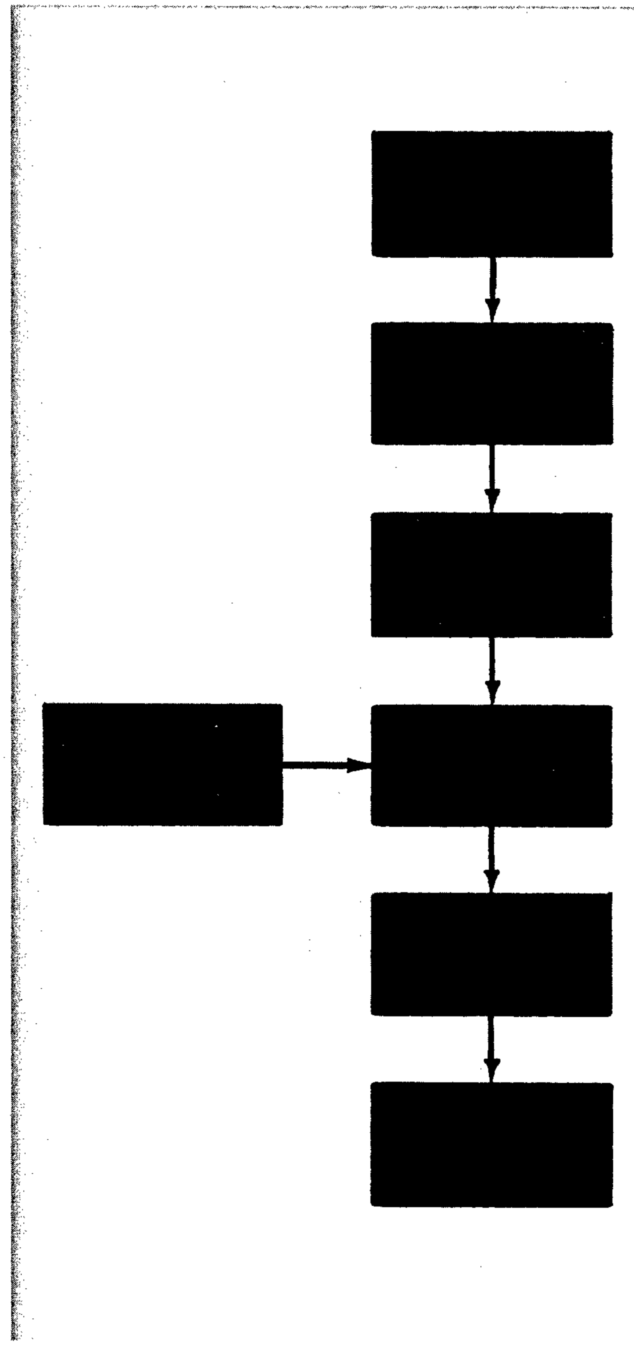


Figure 8

for a raster scan of the component area. Detector measurements are collected and recorded. The entire data array is then used for processing the scatter profile of the test component. The data is further processed for display and storage.

The diameter of the iris opening is adjusted to test for a specific size or arrangement of defect. By scanning over the entire area of the input beam incident on the test system, a mapping of scattering centers can be made. Additional detailed analysis is accomplished for specific areas as needed by altering the iris diameter or the path scanned.

Two sources are provided to cover a wide spectral range from visible to infrared. A tungsten halogen lamp is used to provide a high intensity source from 0.4 to about 2.5 millimicrons. A blackbody source is provided to cover the spectral range in the IR from 1 to about 14 millimicrons. Bandpass filters allow bandwidth selection over a range of 0.4 to 14 millimicrons.

Programmable Controller Used

The programmable controller is permanently connected by cable to the mainframe. The basic system includes a Cromemco Microprocessor Based System. The system is capable of real-time branching based upon test results for a large array of tests. Input can be via keyboard or disk storage. Output can be by way of CRT display, printer, and disk storage. The disk storage is 512K bytes. This allows large programs, result-data keeping, and statistics and inventory control.

The software for the pilot facility is written using assembly language and FORTRAN programming. The devices chosen were selected based upon reasonable cost, ability to add features (peripherals, memory, etc.), ease of programming and low cost, reliability and convenience for using electronics interfaces (analog-to-digital converter packages, etc.).

The software was designed in a highly modular fashion which enabled easier development and maintenance. The basic modules are listed below and subsequently described in the remainder of this section.

- Pre-Test Software
  OTF test
  OTF calibration

- Test Sequence Software
  Translator reset
  Focus
  Peak search
  Focal length
  OTF
  Scatter
  180° rotation
  Off-axis position
  Inventory
  Statistical analysis.

Missile Seeker System

The seeker chosen for the pilot test facility is of the centroid tracking type. It operates in the near IR and is typically tested with a 1.06 mu laser source in a hardware-in-the-loop simulation system.

A series of benchmark tests in the simulation facility were made before the optical disassembly and testing began. The optical components and subassemblies of the seeker were organized for OTF and scatter determinations.

Adaptation of the test facility for specific optical tests required the solution of certain previously identified problems. The first was the initial reference alignment of the optical components or subsystems to be tested. For focus and OTF measurements, an initial axial and angular alignment to a reference on the component is necessary in order that physical parameters be determined relative to the component itself. All tests are then referred to these reference coordinates. By obtaining measurements in a scanning sequence, the actual parameter values can be determined.

One of the design features of the test facility is its ability to adapt easily to a variety of test component configurations. However, certain restrictions were imposed as a result of the physical properties of the test object. Constraints on the optical subassembly to be tested placed restrictions on the translation and scan movements allowed. The mounting of components to be tested is limited by the physical sizes and shapes for which the test assembly is designed. The optical resolution of the system is constrained by the optical quality of the collimator mirror and the angular resolution of the scanning rotation. Each of these parameters was chosen for optimization with the selected seeker. Each system parameter was analyzed quantitatively to determine its design limits and indicate the adaptability of other seekers or component types.

Test Results

The multielement lenses were tested broadboard over their entire spectral range. Focal lengths from 50-135 mm were used. F-numbers ranged from 4-5.6. A replicated aluminum mirror with a gold optical coating designed for a controid tracking missile seeker was tested at a variety of axis angles. A combination system using a mirror and dome assembly was then tested. Optical transfer function information relating to the dome was then derived. In addition to these tests, simulated defects were applied to the mirror entrance pupil such as opaque geometries and

scattering materials. Tests were then run to determine the effects on LSF and OTF. Scattering measurements were also performed on the seeker mirror.

HWIL Simulator Comparison

One of the major objectives of the test facility program is to provide a means for developing optical component standards related to a particular hardware system. To this end, tests were performed on the hardware-in-the-loop simulator. A series of tests were performed using simulated defects of both opaque and diffuse types. Comparison tests were then run on the optical component test system with a similar missile seeker mirror to obtain optical transfer function data for each case.

The missile was fitted with an adapter ring with a 6 inch aperture located approximately 0.25 inch from the seeker dome. The relative position of the adapter ring to the missile body was fixed, while the missile and adapter assembly were gimballed to simulate flight motion. Defect masks were then fitted to the adapter and "flown" in the simulator. The defect masks consist of an array of opaque or diffuse areas of various sizes and densities.

Four masks acquired and tracked well compared to the control mask with no defects. The average miss distance was less than 1 foot in all cases. Two masks, however, sufficiently degraded the optical performance to prevent tracking of the missile seeker during flight. Acquisition of the target was achieved in all cases.

To compare these simulator results to the actual optical performance of the system, line spread functions and optical transfer function data were generated. The same masks were used in combination with a seeker mirror. The optical transfer function for the four masks were very similar in their frequency and phase distribution. They agree well with the OTF obtained for the single mask with no defects. This is consistent with the simulator results, indicating close tracking capability. Two of the four masks, however, showed a clear degradation of the OTF, particularly in the low frequency range of amplitude. Because of the large area and small number of the defects on these masks, OTF measurements were also made off-center such that the center point of the mask was a distance of r/2 from the optical axis, where r is the mask radius. This position corresponds to the maximum contrast in mask position during the simulation. The OTF test results show a major shift in the amplitude response with distinct maximum and minimum. In addition, the phase also changes a full 180 degrees at each amplitude minima.

The test results show a clear correlation between the loss of tracking capability on the flight simulator and the degradation of the amplitude and phase characteristics of the optical transfer function. A few large defects were found to affect the OTF more than a large number of smaller defects. This is due to the nonuniform radial distribution characteristics of the large defect array as well as the nonsymmetrical distribution created as the mask is positioned off-center. The opaque and diffuse mask types yielded little difference in the results, indicating good compensation of the seeker to varying contrast levels.

Considerations for Full Scale Test Facility

One of the design features of the Automated Optical Test Facility is its ability to adapt easily to a variety of the test component configurations. However, certain restrictions are imposed as a result of the physical properties of the test object. Constraints on the optical subassembly to be tested have placed restrictions on the translation and scan movements allowed. The mounting of components to be tested is limited by the physical sizes and shapes for which the test assembly is designed. The optical resolution of the system is constrained by the optical quality of the collimator mirror and the angular resolution of the scanning rotation. Each of these parameters is chosen for optimization with the selected seeker. Since adaptability to other seekers or component types is desired, each system and performance parameter must be analyzed quantitatively to determine its design limits.

With the initial research and development of an automated optical component test facility accomplished, the question arises as to the cost of producing additional testing units. Presented in Table 1 are the individual categories which contribute to the cost of manufacturing an automated optical component test facility. It is assumed here that the time frame and costs are for fabrication only, which requires the largest capital investment. Additional design or programming modifications or installation costs have not been included.

Table 1

Hardware	**$ 45 K**
Technician (3 months @ $25/hr)	**13 K**
Engineer (1 month @ $35/hr)	**6 K**
Documentation	**3 K**
	$ 67 K

Also considered were the costs involved to upgrade an automated optical component test facility.

Etchant Isolation Critical

Semiflexible Thin Film Semiconductors

ROBERT L. BROWN is a General Engineer at the U.S. Army Missile Command in Huntsville, Alabama. His current projects involve creative direction of contractor engineers on projects such as the fully additive manufacture of printed wiring boards (Hughes), ultraviolet curing of conformal coatings for PC boards (Hughes), product cleanliness techniques for PC boards (Martin-Marietta), laser scan testing of PC boards (Chrysler), rigidflex assemblies (McDonnell-Douglas), and insertion of nonaxial lead devices in locaserts (Martin-Marietta), a recent approved success. A Registered Professional Engineer in Alabama and holder of a B.S. in Metallurgy (1958) from Alabama University, Mr. Brown holds six patents and is author of fifteen technical briefs which NASA rates as equivalencies to patents. He was the first recipient of the NASA "Noteworthy Contribution" award in 1970 for his many contributions to their technical utilization program, and patented several inventions that were used in production.

Widespread application in the electronics industry is an important feature of a new method of manufacturing thin film semiconductors that has been developed by the U.S. Army Missile Command. The process is not limited to only the particular semiconductor devices used to demonstrate the technique to industry, but can be used with many types of substrate and semiconductor materials. These can easily be isolated from the etchant reactants used in order to prevent damage to the item.

The new manufacturing technique is the outcome of an MM&T project conducted for MICOM by MicroElectronics Corporation of Auburn, Alabama. Initially planned as a two phase project involving the application of photolithographic methods for producing reproducible thin film transistors of highly reduced geometries, the project was widened in scope before its completion to include the development of manufacturing techniques for fabricating them on semiflexible substrates.

The first phase of the project consisted of a developmental effort devoted to the assessment, selection, and qualification of materials and processes suitable for fabrication of thin film transistors. The major milestones of this basic effort were to

- Design the manufacturing facility
- Specify and purchase equipment
- Receive and install equipment
- Develop the initial manufacturing procedure and processes
- Verify the procedures
- Document the progress.

This basic effort extended over a twelve month interval.

NOTE: This manufacturing technology project that was conducted by MicroElectronics Corporation was funded by the U. S. Army Missile Command under the overall direction of the U. S. Army Directorate for Manufacturing Technology, DARCOM. The MICOM Point of Contact for more information is Robert L. Brown (205)876-5879.

The option effort was a continuation of the initial manufacturing methods and technology of the basic effort. The major milestones were related to the

- Solution of identified problems
- Establishment of design criteria
- Manufacture of demonstration devices
- Cost analysis
- Industry demonstration.

This option effort occurred over a twelve month interval.

An addition to the original scope of the project occurred in the middle of the option phase. This effort required the manufacture of thin film transistors on two different substrates to establish the manufacturing technology of thin film transistors on semiflexible substrates.

Results Summarized

The project ultimately determined that

- Manufacturing methods/technology were developed to build thin film transistors with an improved metal masking technique. The critical source-drain spacing of this technique is defined photolithographically, while the semiconductor, insulator, and gate metallization are defined by metal masks.
- The manufacturing methods and technology was developed to build thin film transistors with an all photolithographic masking and etch technique.
- The ease of manufacture for the improved metal masking and the photolithographic methods were demonstrated using production techniques and production equipment.
- The manufacturing methods and technology for photolithographically produced transistors can be accomplished using equipment common to the semiconductor industry. No special modifications to normal equipment is necessary.
- The enhanced producibility due to reduced manufacturing steps and also the low temperature of the process results in a low cost, high yield manufacturing method.
- Thin film transistors can demonstrate significant levels of strain sensitivity.

Versatility of Properties

The unique properties of thin film transistors provide for a wide range of applications. The transistor characteristics typical of present monolithic device technology can be implemented with thin film transistors. The thin film approach provides a means of constructing transistors on any insulating substrate that will withstand the temperature and chemical environments of processing. The applications in such areas as sensors and displays are an excellent use of the thin film transistor properties. The fabrication of transistors over large flat areas produces a display with transistors for switching at the picture elements. This technology along with thin film electroluminescence techniques can result in flat panel displays of unique properties for applications in military battlefield, cockpit, and tank control displays. The light and strain sensitivity of thin film transistors makes applications in image and transducer technology an excellent area. The use of these sensors and transducers to detect light and measure pressure, force, or acceleration are possible implementation applications.

Typical generic applications which will use these devices include guidance and control sections of missiles and projectiles, aircraft and ship control systems, and field station information and control equipment. The basic properties of thin film transistors also make it possible to replace standard transistors with thin film transistors. The applications, therefore, become very broad with regard to their use.

Design Aspects

The thin film transistor functions as a metal oxide semiconductor (MOS) device. The three terminals of the device are termed the source, drain, and the gate. The material evaluated and used throughout this manufacturing methods and technology study was cadmium selenide, which as deposited forms an n-type material (majority carriers, electrons). The transistors operate as an enhancement mode device. The current flowing from the source to the drain was enhanced by an application of positive voltage on the gate.

The design aspects relate to the processing considerations necessary for the electrical performance of a device. The parameters of transconductance(the change in drain current as a function of gate voltage), operating voltage, and current are key performance variables. The channel length, the width-to-length ratio, the semiconductor and insulator thicknesses, the effective mobillity, and the gate capacitance are controlled by the processing. Figure 1 shows normalized thin film transistor characteristics.

Physical Effects On Performance

An important correlation must be made between the processing of the device and the actual characteristics obtained. The thickness of the semiconductor, the annealing time and temperature of the devices, and the step coverage of the particular layout all can influence the operation of the transistor. The most critical design aspect that is encountered is the smooth transition from one interface and layer to another. The step coverage of the source drain makes deposition of the semiconductor difficult. Accurate thickness control of the gate insulator is also necessary to ensure adequate breakdown voltages. The effective mobilities determined from actual device operation are

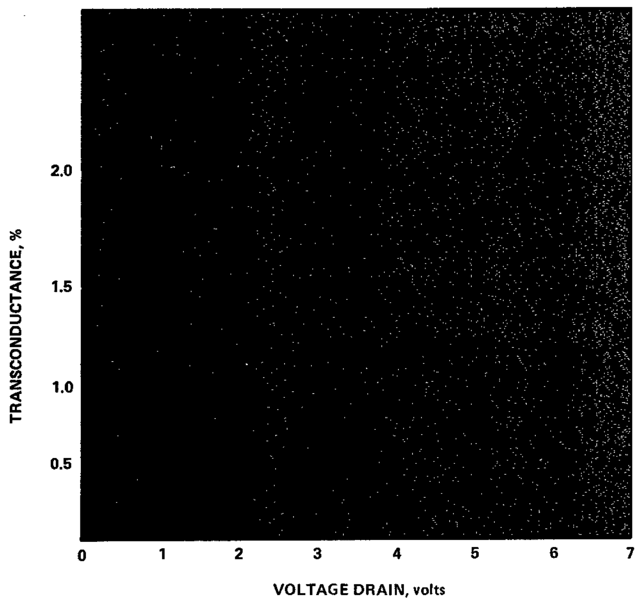


Figure 1

typically 30 cm^2/V-sec. The photolithographic technique allows channel lengths of down to four microns with aspect ratios of 800 as a typical demonstration device. The gate oxide thicknesses can vary from 200 to 1000A.

Third Phase Added

The primary objective of this manufacturing methods and technology effort was establishment of improved design and processing techniques for the manufacture of thin film transistors.

The basic effort was directed at the selection of the equipment, processes, and materials. The objective of this task was the initial planning and evaluation of the proper approach to the manufacture of thin film transistors. A major milestone to be accomplished was the development of a design for a computer controlled manufacturing facility for evaporated thin film transistors. Following the design effort, the objective of developing an automated system including the control of processes, materials, deposition conditions, and masking was to be accomplished. The basic effort also included an objective of developing interconnection, crossover, resistor and capacitor procedures, and parameters. The final objective of the basic effort was the verification of the complete system by development of a normal operating procedure.

The option task had as a central objective the firm establishment of the manufacturing method. The solution of problems and inconsistencies in device performance was a major objective of this task. Important correlations between the device characteristics and processing parameters were established. The option task also included completion of all the documentation of the equipment used to manufacture the transistors. The design criteria for the manufacture of the devices and the corresponding performance was to be completed in the option task. The final objective of the option task was to perform a cost analysis and an industry wide manufacturing process demo.

The addition to the scope of the option task included a characterization of thin film transistors on flexible substrates. The strain sensitivity evaluation of two sets of 100 small signal transistors on semiflexible substrates was a major task objective. The correlation of process parameters to this strain sensitivity was also a significant portion of the effort. The manufacture of thin film transistors on alternate substrates of various oxides was included as an objective of the task.

BASIC EFFORT

Equipment Selection

The basic equipment can be described as being composed of four major items. They are (1) the vacuum system, (2) the sources, (3) the process controller, and (4) the computer. The selection of the equipment for the manufacture of thin film transistors in a computer controlled system is a complex issue, with the equipment selected highly dependent upon the specific process used. The interaction of the equipment is a key element, with the utmost care necessary when the interface compatibility is considered.

Vacuum System. A complete review of available vacuum system suppliers was performed to determine the most applicable system configuration. The requirements placed upon this program with regard to a manufacturing methods and technology effort made small laboratory vacuum systems unacceptable. The attainment of vacuums in the 1×10^{-7} to 1×10^{-8} torr range was determined to be sufficient for the manufacture of thin film transistors. This was due to earlier research and development activity at Auburn University and elsewhere that resulted in the construction of thin film transistors with an oil based diffusion system.

The ultrahigh-vacuum systems with pumping modules other than oil diffusion systems were eliminated early in the evaluation effort due to their additional expense, and the confidence that devices would be fabricated with an oil based system.

The use of a rather large vacuum chamber so as to perform multiple depositions using several sources and mask changing mechanisms required careful evaluation during equipment selection.

Sources. The evaporation source for the material was evaluated with regard to the process and the vacuum system selected. From earlier published data and research work performed at Auburn University, it was determined that several resistive sources and a multiple hearth electron beam gun should be selected.

The selection of the electron beam gun and its associated power supply was performed with due consideration of the vacuum equipment, fixturing, and the fabrication processes. An electron beam gun with a minimum of four pockets—with each well or pocket having a volume of 30 cubic centimeters—was required. Two suppliers were determined to have equipment with adequate performance and maintenance history. The use of the deposition con-

troller also added to the selection criteria for the electron beam gun.

The resistive sources were of the filament type of design. The resistive source for the semiconductor was of the tantalum boat design, which allowed for the complete evaporation of the material without condensation on lower temperature locations of the source. The vacuum system was equipped with a 2.5KVA power supply with 5, 10, 20, and 50 volt taps. This power, which was connected to the filament or boat, was controlled by a 0-10 volt analog voltage. The deposition controls provided a signal that controlled the power to the resistive source with this 0-10 volt signal.

Deposition Controller. The control of the material thickness parameter is an excellent means of controlling the properties of a thin film material. The change in thickness with respect to time will provide the deposition rate. This deposition rate is an important property which is directly related to film nucleation and growth and therefore the electrical and mechanical properties. The monitoring of thickness and its corresponding control is performed by several different techniques. The change in conductivity or light absorption has been used to produce information on film thickness. One of the most effective means of determining thickness is the change in a crystal's oscillating frequency as material is deposited on its surface.

Deposition controllers using thickness information from an oscillating quartz crystal to determine deposition rate information are one of the most reliable and automated types. The features provided in such a controller allow for the control of temperature and time dependent power functions and rates of deposition. An evaluation of commercially available controllers indicated units that were the most advanced and compatible with an overall host computer. The computer selected is a microprocessor based system that has a well structured computer language feature. In addition, the access of up to 23 input and 23 output lines to control additional tooling or derive data as to the deposition in progress is available. A distributed system is used to control and monitor the deposition while a central computer can be used to decide alternate paths or derive and signal critical process changes. The system also can operate under an established program as defined in the microprocessor and thus not require the extensive software development typical of many computer controlled facilities.

Computer. The evaluation of a compatible computer facility with the proper configuration of input and output hardware, CPU, disk, and memory was performed to a large extent with the aid of Dr. Victor Nelson, Head of the Computer Laboratory of the Electrical Engineering Department, Auburn University, Dr. Nelson recommended and subsequent evaluations confirmed the suitable system for the computer controlled function of this manufacturing methods and technology effort. The computer system would be configured with a video terminal and keyboard for I/O along with a 30M byte disk drive and 96K of memory. With this selection of computer hardware, the communication between the computer and the deposition controller could be performed via serial interface. The only restriction on the interface port was that it must support the standard "handshake" signals of

DSR—(data set ready)—from controller to host computer to indicate readiness to receive data.

DTR—(data terminal ready)—from host to controller to indicate readiness of host to receive data.

The development of the software to control the deposition system and all of the associated support and tooling was a major task of the option phase of the total program.

System Design. The overall system configuration is shown in Figure 2. The computer can maintain control of all functions

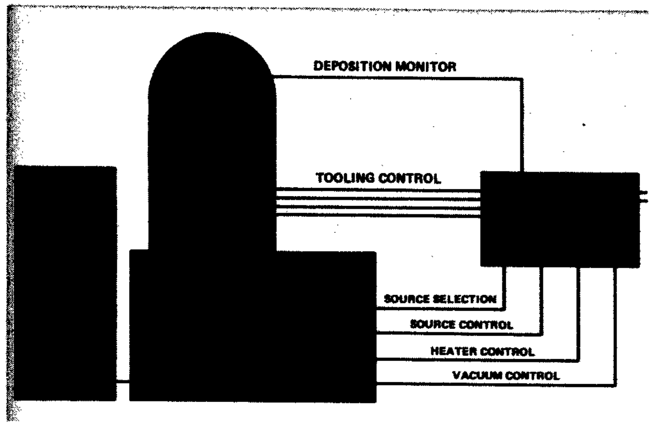


Figure 2

while critical processes are directly controlled by the deposition controller. This system was considered to be the most effective for the MM&T effort due to the reproducible and economical tradeoffs possible. The equipment is standard hardware, which should facilitate the technology transfer process. The computer control will provide decision options to be exercised and, therefore, increase the yield of the complex multistep process used in thin film transistors.

Tooling. The use of metal masks as stated in an earlier section of this report requires careful design and system integration to insure proper manufacture of thin film transistors. The tooling for this effort uses bimetal masks manufactured to an accuracy of 50 millionths of an inch. The metal masks have openings that provide an exact shadowed pattern on the surface to be deposited.

A key feature of the project was the manufacturing method developed during the basic effort which resulted in elimination of the total metal mask tooling concept. A complete photolithographic process was developed which provided a means of manufacturing thin film transistors, with alignments and exposure accomplished using a standard integrated circuit aligner. The productivity and manufacturing simplicity associated with the complete photolithographic process were a result of an effort to optimize the manufacturing techniques. The finalized construction of a computer operated metal mask changer approach was prioritized below the development of a more manufacturable photolithographic method. Over 20,000 metal masked thin film transistors were manufactured and their performance evaluated.

The metal mask fabricated thin film transistors thus were built on noncomputer automated tooling, but using the process steps and tools that would have been utilized if the automated mask changer was completed. The tooling for the deposition of non-patterned films to be used with the photolithographic manufacturing process was accomplished in the vacuum system by using a planetary substrate holder. The planetary revolved about the sources and rotated on a water cooled ring. The drive power for the planetary was accomplished by the use of a variable speed motor with a feedthrough in the top of the bell jar.

System Integration. For the interconnection of the critical equipment, the vacuum system, the deposition controller, and the computer, system integration is related to the functions that occur within the vacuum chamber. The data from the crystal oscillator is supplied to the deposition controller by a coax cable. The control of each source of deposited material can be selected from the deposition controller according to a specified algorithm. The control of the source power from 0-100% is also a significant feature of the system. The setting of temperature and the signal to start or stop the vacuum pumping action is via the deposition controller. The safety interlocks that insure cooling water flow and the proper pressure in the system are also part of the integrated manufacturing system.

In the metal masking design, the tooling required to hold the substrate and the metal mask are aligned to each other with tapered alignment pins. The substrate and the metal mask are prealigned to these pins to insure accurate manufacture of thin film transistors. A carousel rotates the substrate and the mask holder into approximate alignment. The mating assembly is pushed together to achieve final alignment of the substrate to the mask.

Fabrication Process. The manufacture of thin film transistors has been accomplished in a number of ways since the work of Weimer. Two different fabrication processes for thin film transistors are identified as the metal masking process and the photolithographic process. Typical metal masking techniques in the past have relied on the use of metal masks to define the source drain spacing. This technique therefore allowed the definition of all the transistor elements within the vacuum system with one pumpdown. The metal masking technique described in this report uses an innovation in the earlier process by defining the source drain spacing photolithographically and, therefore, providing a more accurate control of the critical spacing. The use of the photolithographically defined spacing provided for a channel length down to four microns, with seven microns being the typical high volume design standard.

With the results of the photolithographically defined source drain spacing, additional work was performed to define the entire thin film transistor photolithographically and thereby eliminate all metal masks from the process. The topology design and material cross section of the device had to be changed to accommodate the new process, but accurate seven micron channel lengths with a length to width ratio of over 800 to 1 were possible.

Material Selection. The materials for the manufacture of thin film transistors were a very important design consideration. Although semiconductor devices with cadmium sulfide have been produced, the sensitivity to the processing parameters of substrate temperature and source temperaure made evaluations with cadmium selenide more reproducible and manufacturable. The manufacture of thin film transistors made from cadmium telluride as well as indium antimonide have been demonstrated; however, the hazardous nature of the tellurium appeared to outweigh the performance characteristics for a manufacturing method.

The contact to the semiconductor was an important element in the selection of material. After an evaluation of the typically used systems and the results of research in this field which has related the degradation with time of thin film transistors to diffusion of the contracts, chrome was selected. The ohmic contact of chrome to cadmium selenide provides a stable controlled transistor if proper care is used to avoid chromium oxide and excessive internal stress.

The use of an insulator material that can be purchased with high purity and deposited to provide a high dielectric strength was necessary. The use of silicon monoxide, which is easily evaporated and readily available, was evaluated along with aluminum oxide. The aluminum oxide (sapphire) provided the best quality gate insulator for the thin film transistor.

The use of aluminum as a bonding and interconnection metallization was selected due to the ease of evaporation, good ohmic properties, and the economical advantages over gold. Improved metallization configurations using sloped etching made contact with aluminum and excellent process parameter. Another processing advantage of aluminum is the activation of chromium etching processes due to the electronegativity difference provided by the aluminum to chromium bimetal couple.

Metal Masking Process. The transistors fabricated using the metal masking process used a structure that provided for the source and drain on the lower layer of the device. The structure then had the cadmium selenide, the aluminum oxide, and the final gate metallization deposited through metal masks. Figures 3 and 4 illustrate the sequence of processing steps and a cross section of the device.

The first step in the fabrication process is the cleaning of the substrate. Following the cleaning process, the source drain metallization is deposited. The substrates are placed in the vacuum system and pumped down to a vacuum of 1×10^7 torr, with the substrates heated to a temperature of 100 C. The aluminum oxide is conditioned with the shutter closed so as to form a pool of liquid material in the center of a sapphire crystal. The deposition of the aluminum oxide substrate barrier occurs when the shutter is opened. The deposition rate of seven angstroms a second is used to deposit a total thickness of 1000 angstroms of material. Following the deposition of the substrate barrier material, the chromium for the source drain metallization is deposited.

The chromium source is rotated into position in the electron beam gun and the chrome is deposited and defined according to the MEC process.

The substrate is aligned to the metal mask for the cadmium selenide deposition. The MEC process describes this semiconductor deposition.

Following the cadmium selenide deposition, the metal mask for the gate insulator is positioned and the gate deposition is performed. The MEC process describes this semiconductor deposition. Following the gate insulator deposition, the metal mask for the gate metallization is positioned and the gate deposition is performed. The MEC process also describes this deposition.

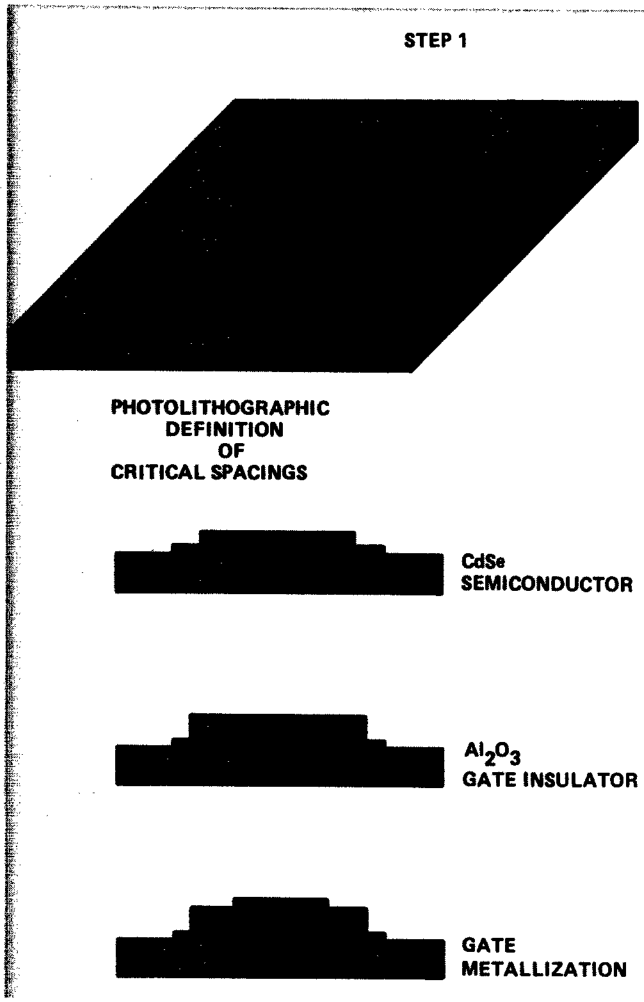


Figure 3

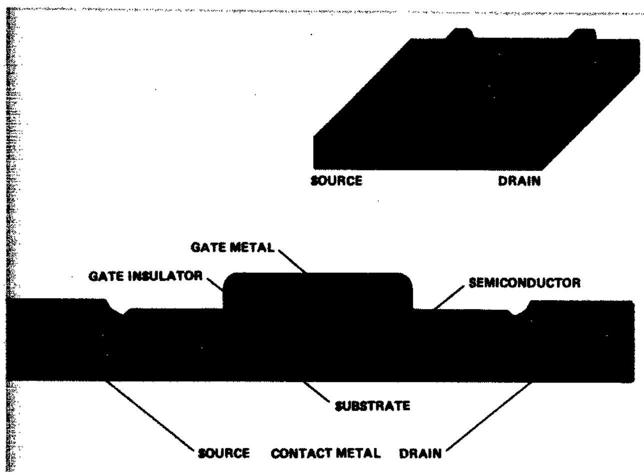


Figure 4

Figure 5 shows the design of a typical thin film transistor metal mask set. The design of the source and drain which were discussed in the earlier explanation of the metal mask approach results in a photolithographically defined chromium metal pattern. The metal mask for the semiconductor is aligned to the source drain metal. The final stage of Figure 2 shows a composite drawing of all the layers in alignment.

Photolithographic Process. The transistor fabricated using the photolithographic process uses a structure that provides for a metal gate on the substrate with the gate insulator semiconductor and the source drain metallization as the top layers of the device. Following the definition of the gate metallization as shown by the gate mask of Figure 6, the substrate is placed back in the chamber and the film of insulator, semiconductor, and contact metal are deposited onto the substrate.

OPTION TASK

In the option task of the effort, the routine manufacturability of the materials and processes of the basic effort was established. The key elements of the option task were the definition of the design aspects of thin film transistors, the proof of the manufacturing method by demonstration devices, and an evaluation of the cost of manufacture and an industry demonstration of the manufacturability of thin film transistors. The option task was initiated at the completion of the basic effort.

Design Aspects. The thin film transistor functions as a metal-oxide-semiconductor (MOS) device. The three terminals of the device are termed the source, drain, and the gate. The material evaluated and used throughout the manufacturing methods and technology study was cadmium selenide, which as deposited forms an n-type material (majority carriers, electrons). The transistors operated as an enhancement mode device. The current flowing from the source to the drain was enhanced by an application of positive voltage on the gate.

The design aspects relate to the processing considerations necessary for the electrical performance of a device. The parameters of transconductance, operating voltage, and current are key performance variables. The channel length, the width-to-length ratio, the semiconductor and insulator thicknesses, the effective mobility, and the gate capacitance are controlled by the processing.

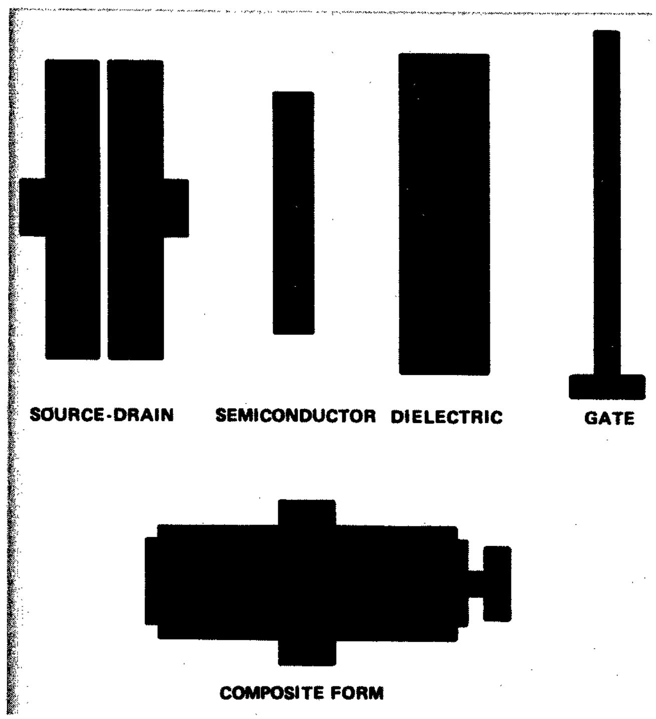


Figure 5

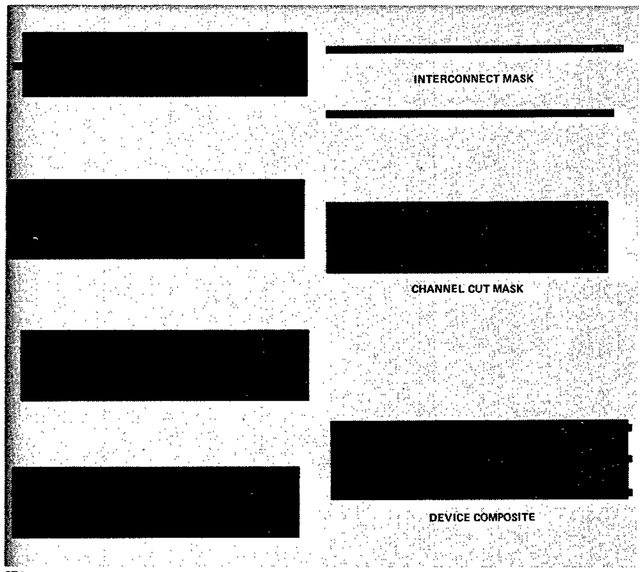


Figure 6

Demonstration Devices. The manufacture of devices that demonstrate performance according to the design aspects was a major task of the option effort. Extensive experimentation and process evaluation was performed to determine the proper processes for manufacture of the thin film transistors. The evaluation of process parameters such as temperature were an important element of the experimentation. The substrate temperature plays a very important role in the nucleation and growth kinetics of thin films. Evaluation of the combined effects of substrate temperature and deposition as related to substrate temperature provided an excellent insight into the combined effects of subsequent thermal histories on previously deposited films, especially semiconductors. The electron beam evaporation of aluminum oxide can generate significant levels of chamber heating, which was shown to be an important parameter in the manufacturing process.

The control of the deposition rate and total thickness of the gate insulator was an important processing variable, not only from the breakdown voltage aspects but also from the contact potential and thermal history considerations. The use of the proper combination of chamber pressure to insure minimal oxidation of the chromium—along with the substrate temperature and deposition rate of the cadmium selenide—were found to be critical to insure good ohmic contact.

The oxidation of the chromium beyond the specific limits of the process control resulted in low current carrying capability, with a corresponding distribution of voltage (source to drain)—a strong function of the path length. On some occasions, the current paths of the transistor could be seen as overheating-promoted diffusion and discoloration of the source-drain metallizations. The aspect of material purity cannot be overemphasized. The presence of even very small quantities of conductive material such as carbon, aluminum, or earlier depositions of cadmium selenide can severely alter the insulative properties of aluminum oxide. To insure consistent performance, the material for the insulator was examined and cleaned. The melt typically was formed in the center of a single crystal of the sapphire material.

Physical Design. The demonstration devices were fabricated with a variety of layouts. Two different transistors, each with a different source to drain spacing, were fabricated, a single channel device and an interdigitated metal mask fabricated structure. In this device, a common gate connection bar is provided when the source and drain metallizations are fabricated. This is necessary due to the structure that must be used when designing metal masks. A structure such as the multiple gates (which typically are long and narrow) must be supported on both ends of the mask for dimensional stability. This design is actually four transistors connected in parallel. The interdigitized structure allows for common connection of multiple sources and drains.

With the demonstration devices using the photolithographic fabrication technique, source-to-drain channel is produced by final etching of a uniform chromium deposition. This source-drain (channel) spacing was designed for maximum length by using the interdigitated design. The structure is an inverted gate, thus providing metallization under the bottom of the transistor. To insure that there would be no gate-to-semiconductor shorts around the outside edges of the structure, the insulator mask was designed to cover and extend beyond the gate metallization. A step in the fabrication process exists for gate contact. This provides electrical connection to the gate as well as the source and drain. The semiconductor contact metallization of chromium is enhanced by the use of aluminum to reduce resistance and thereby improve the current carrying capability of the transistors.

Electrical Performance. The transistors had a range of properties dependent to a large extent upon their processing history. There were two basic ranges of transconductance—the largest body of electrical data was derived from the transistors with transconductance of 10 to 300 micromhos. Shown in Figure 7 is the transistor characteristics device. The transconductance of this device is 100 micromhos.

The distribution of transconductance is shown in Figure 8 for one manufacturing lot. The transistor had well developed saturated characteristics. The gate breakdown voltage was greater than 25 volts. Maximum drain currents of up to 10 milliamperes

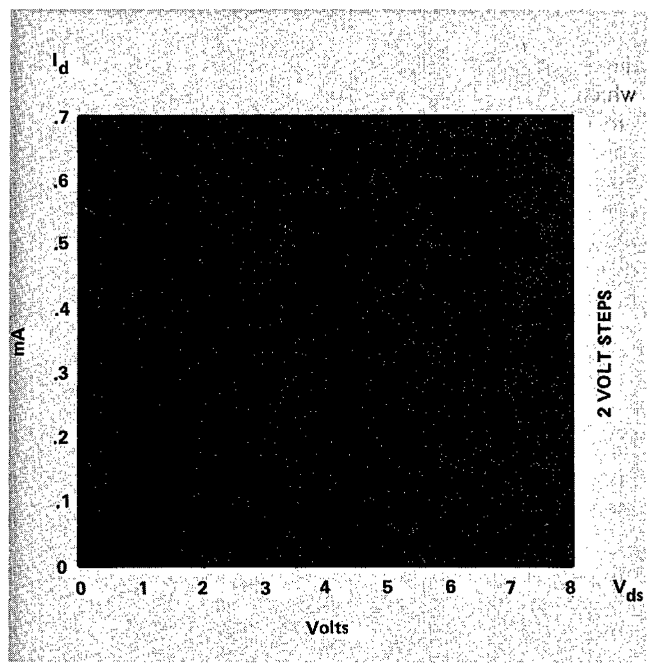


Figure 7

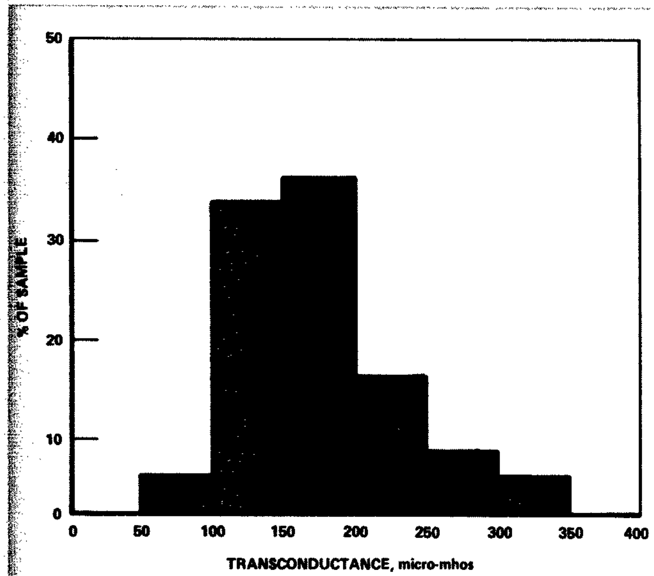


Figure 8

could be passed through the device before self heating and current crowding caused degradation in the device characteristics.

The evaluation of 50 lots of transistors fabricated using metal masks (giving a total of approximately 20,000 transistors) showed a range of transistor characteristics with nominal values of those shown in Figure 7. The breakdown voltages of the gate-to-source was 35 volts, except for situations where inadequate gate insulator thickness or step coverage resulted in leaky gates or low breakdown. An equivalent number of photolithographically defined transistors were fabricated. The increased aspect ratio of the source-drain channel provided higher gain devices.

Cost Analysis. The trend of constantly decreasing microelectronic manufacturing costs has been well established. The major elements in cost reduction (yield, lower packaging costs, higher volume) have continually improved to counterbalance increasing overhead. The analysis of manufacturing cost consists of direct material, direct labor, and manufacturing overhead. Factors which affect the cost of specific devices are the film deposition processes, substrate size, size of the devices, number of interconnections, package material, and yield throughout the production process. The variables that occur among competitors within the industry segment of interest are due to labor rates and utilization, equipment efficiencies, control of overhead, and degree of automation. Within the total manufacturing process, there are three major production costs: (1) substrate fabrication and die probe; (2) assembly; (3) final testing and finishing. This manufacturing methods and technology task was related to the manufacture of thin film transistors. The assembly and final testing and finishing of thin film transistors and conventional microelectronic devices are similar. Cost analysis therefore only considered the substrate fabrication and die probe as the manufacturing process for evaluation.

Transistor fabrication consists of various deposition, masking, and etching steps; cost variations among different circuits are due to the differing number of processing steps, tolerances allowed (especially in mask alignment), and metal interconnect layers. Yield losses in substrate fabrication are caused by breakage, masking misalignment, contamination, and operator error. Some of the substrates rejected at in-process inspection stations can be reworked to keep overall substrate yield between 60% and 80%.

With identical substrate costs, the die cost varies directly with the number of good electrical die per substrate, which is the result of the total available die per substrate multiplied by the probe yield. A 0.020 inch by 0.020 inch die size will result in 10,000 die per two inch by two inch substrate. The electrical probe yield experienced in this study was used in this cost analysis was 80%. Therefore, the final die (20x20 mils) per substrate were 8,000 die. The cost per die of the metal mask processed devices was 0.0053 dollar and the photolithographically defined transistors was 0.00394 dollar. As the production lots increase from the single substrate of this example to production lots of 10 and 100, the reduction in cost occurs due to the labor of Table 1. Therefore, a 50% reduction

	Metal Mask	Photolithographic
1. Starting Material 2x2 glass	$ 0.60	$ 0.60
2. Masks	8.50	2.00
3. Chemicals, D.I., H_2O, Gases	2.75	2.75
4. Labor (U.S.) $6.50 average at 200 % overhead	19.50	16.50
5. Equipment Depreciation (5 years)	5.00	5.00
	$36.35	$26.85
Average cost due to substrate processing yield	6.36	4.70
TOTAL	$42.71	$31.55

Table 1

in labor for each production size of 10 and 100 will result in new substrate costs of $31.26 (10), $25.53 (100) for the metal mask fabricated devices and $21.85 (10), $17.01 (100) for the photolithographically process substrates. The price per die will, therefore, be reduced. Table 2 summarizes these calculations and is provided for comparison purposes only—exact amounts are a function of specific designs and manufacturing methods.

Die Quantity	Metal mask Technique	Photolithographic Technique
10,000	0.533	0.394
100,000	0.391	0.273
1,000,000	0.319	0.213

NOTE: This table is provided for comparison purposes only—exact amounts are a function of specific designs and manufacturing methods.

Table 2

MODIFICATION TASK

The results of the option task indicated that additional effort in the manufacture of thin film transistors should be directed at the investigation of the strain sensitivity aspects. Published

reports by R. Muller showed that thin film transistors could exhibit an additional gate effect when the transistor is strained. The transistor demonstration devices of this project were fabricated using the metal masking process; the use of a special metallization interconnecting pattern made electrical probing during strain possible. Devices with source drain spacings which were parallel to the strain were probed as well as film transistors that were perpendicular to the strain.

Electrical Performance. The strain sensitivity of the thin film transistors was evaluated by examining the change in drain current as a function of strain. The test tool shown in Figure 9 was used to produce a given deflection in the substrate. The deflection was correlated to the strain using the standard equation for beam deflection. Shown in Figures 10 and 11 are the results of the strain versus drain current experiments.

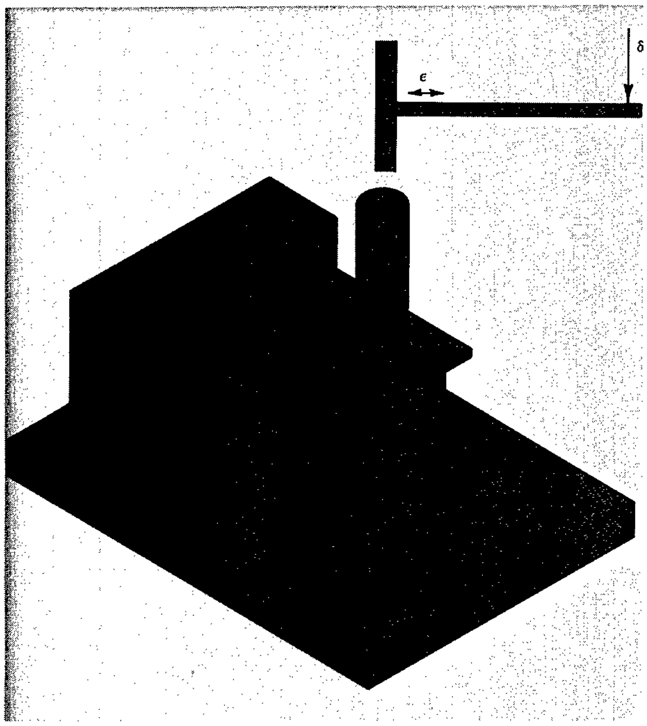


Figure 9

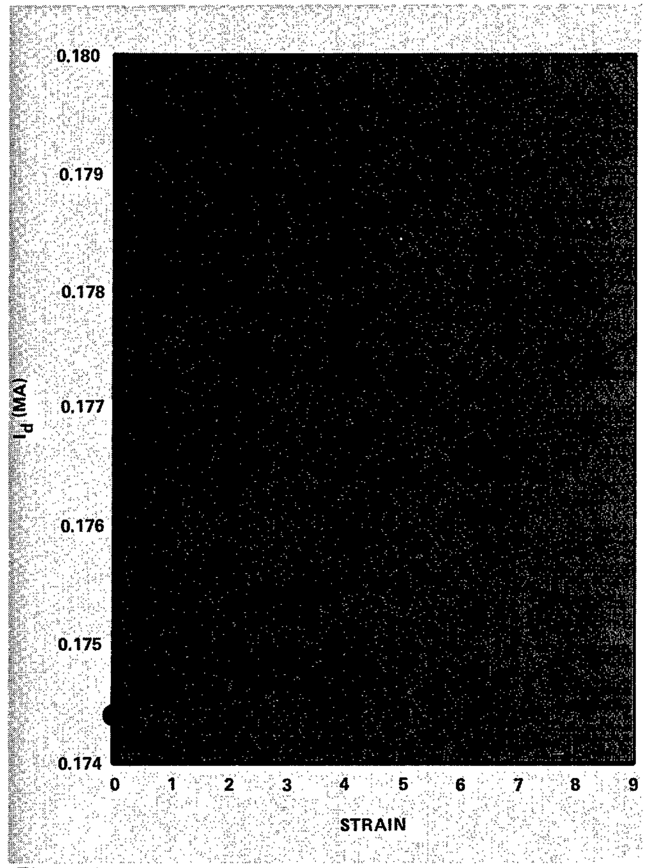


Figure 10

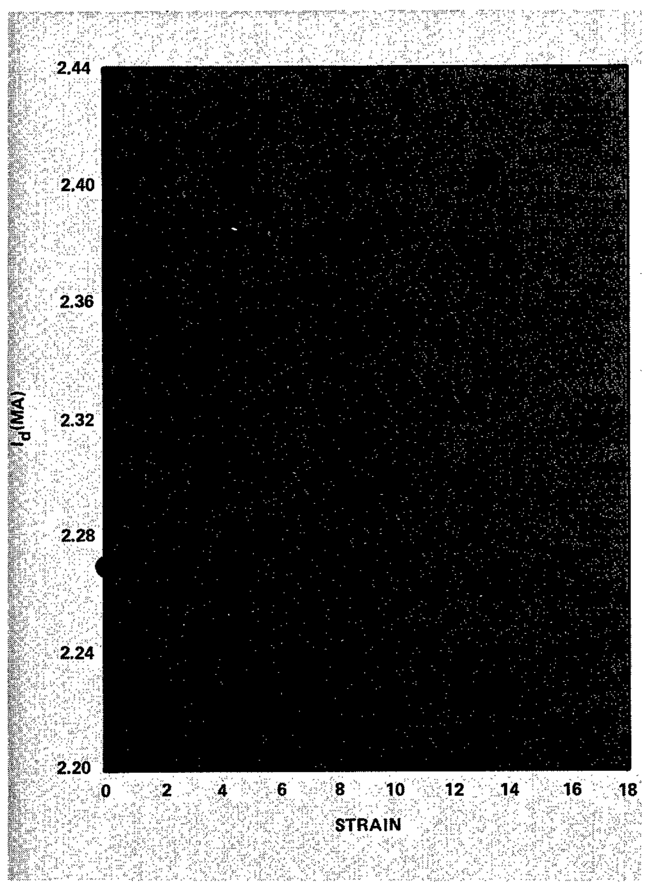


Figure 11

More Versatile and Reliable But Smaller

Transistors have made possible electronic systems of great complexity which perform functions such as communications, control, data processing, and signal processing. The functions have continued to increase in complexity while the space available for them has generally decreased. The applications, especially in the military, have been a forcing function to require ever increasing complexity and decreased size and weight along with reliability. This article has considered the manufacturing methods and technology of thin film transistors which enable the manufacture of a transistor or similarly a circuit of transistors on any type of insulating substrate.

The thin film transistor described is an insulated gate field-effect transistor in which the current is modulated by the same principle as in silicon MOS transistor. The differences are basically in the properties of the materials, the thin film and polycrystalline nature of the semiconductor, the modes of conduction, and the oxide semiconductor interface fabrication.

Positive Advance Mode

The unique manufacturing method of this project was the application of photolithographic methods for reduced geometries and ease of manufacturability. Manufacturing methods and technology efforts that have been funded in the past used metal shadow masks for the definition of the films. The use of shadow masks required carefully constructed mechanical tooling configurations to insure the proper sequence of alignments and material depositions. Here, photolithographic techniques were developed to define the critical source-drain spacing and also (in an alternate manufacturing method) the complete thin film transistor. The manufacturing method using photoresist and visual alignment results in better device characteristics with a more manufacturable method.

Recent trends requiring lightweight, compact electronic systems have led to miniaturization with unique packaging configurations. To achieve the required high-density electronic packaging with design performance, the development of thin film transistors has been identified as an important element. The manufacture of thin film transistors on substrates of many different configurations can provide a multitude of alternate packaging techniques. The use of insulating substrates that do not function as a circuit element, but simply provide mechanical support, therefore can provide low cost manufacturing solutions to the single crystal silicon substrates in common use today. The special properties of glass as both a substrate and a display medium is a typical application of thin film transistors for flat panel display technology. To increase the miniaturization and manufacturability of electronic equipment and produce unique designs and more functional systems, the United States Army Missile Command has funded this manufacturing methods and technology program for thin film transistors.

More Advances Possible

The results of the project have demonstrated improved manufacturing methods and technology for the fabrication of thin film transistors using metal masking technique as well as the photolithographic technique. The theoretical gain possible is much greater than the realized values, due in large part to imperfections in the polycrystalline nature of the semiconductor. An application of more advanced techniques of semiconductor technology, such as ion implantation and plasma assisted vapor depositions and etching could be applied to the manufacturing methods developed. Improved control of polycrystalline semiconductors used in the manufacture of thin film transistors would improve their characteristics.

Tests have been conducted of the class of transistors manufactured by this process; these tests point up some highly significant properties of the items: (1) the transistors function well at liquid nitrogen temperatures; (2) they also will operate for a limited time (20 min) at 300 degrees Centigrade; (3) they exhibit complete immunity to moisture damage—complete immersion for extended periods of time will not lessen their performance after drying.

The top voltage for which they've been designed to date is 1000 V, but higher voltages of operation are simply a matter of design.

Editor's Note: Readers may obtain more information by acquiring a copy of U. S. Patent No. 4,398,340 assigned to R. L. Brown—a generalized method of inexpensive manufacture of semiflexible thin film transistors.

Brief Status Reports

Project 3708. Coated Fabric Collapsible Fuel Tank Program. Circular seamless test and evaluation program initiated at YPG on 2 prototype seamless tanks. One tank filled with fuel/H_2O mixture and the other only H_2O. After 6 months, both tanks were in excellent condition with no signs of deterioration of the coated fabrics. For more information, contact K. K. Harns, BRDE, (703) 664-5433.

Project 3717. High Temperature Turbine Nozzle for 10 KW Power Unit. Engine testing of ceramic nozzle assemblies was initiated. Fifty hours of operation was accumulated on the first nozzle assembly. For more information, contact J. Arnold, BRDE, (703) 664-5459.

Project 3743. Composite Spun Material Launching Beam for Bridges. Technical work has been completed. Project complete. Structural beam elemments have been produced using winding techniques. Methods for mass producing complex pin joints have been developed and demonstrated. The final technical report detailing the process has been prepared. For more information, contact R. Helmke, BRDE, (703) 664-5176.

Project 7200. Composite Engine Inlet Particle Separator. All technical work is completed. The final technical report is available. For more information, contact Bill Brand, AVRADCOM, (314) 263-3079.

Project 7241. Hot Isostatic Pressed Titanium Castings. Production of low cost blackhawk damper bracket using HIP and heat treated titanium investment casting. This bracket will be interchangeable with the present forged bracket. For more information, contact Bill Brand, AVRADCOM, (314) 263-3079.

Project 7286. High Quality Superalloy Powder Productiion For Turbine Components. Effort initiated with ingot processing by electron beam remelt. For more information, contact Bill Brand, AVRADCOM, (314) 263-3079.

Project 7300. Improved Low Cycle Fatigue Cast Rotors. Material screening testing complete and final proces selected. Casting vendor producing next lot of castings for material test evaluation and field engine testing. For more information, contact Bill Brand, AVRADCOM, (314) 263-3079.

Project 7351. Composite Shafting for Turbine Engines. A technical report presents the Phase 1 work accomplished. After a review of Phase 1 results, approval was granted to proceed with Phase 2. Fabrication of a full scale diameter, one-half length shaft was initiated. For more information, contact Bill Brand, AVRADCOM, (314) 263-3079.

Project 7412. Infrared Detector for Laser Warning Receiver. Confirmatory and pilot run samples indicate a yield from 30 to 70 percent. These INAS IR detectors will be used in the AN/AVR-2 program. Will build and test interdigitated IR detectors for AN/AVR-2 program. For more information, contact Bill Brand, AVRADCOM, (314) 263-3079.

Project 7415. MMT T700 Blisk Repair. GE has obtained 26 blisks. Welding operations have been defined. The heat treat cycle has been selected. Corrosion and high cycle fatigue test plans have been formulated. Design of tooling for weld and heat treat is complete and on order. For more information, contact Bill Brand, AVRADCOM, (314) 263-3079.

Project 3050. Epitaxy of III-V Semiconductor Photodetectors. RCA of Canada contracted thru Canadian Commercial Corp. to establish methods for making photodetector modules for AN-GAC-1 long haul and AN-TYC-39 local fiber optic communications systems. Liquid or vapor phase epitaxy of IN-GA-AS-P were used. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3056. Electroluminescent Numeric Modules. Rockwell installed 18 in. and 24 in. thin film vacuum deposition chambers for electroluminescent numeric display modules. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 3073. Tactical Graphics Display Panel. GTE Corporation experienced row shorting problems in fabricating 10 x 12.5 inch thin

film electroluminescent display panels. Diagnostic tests are under way. Drive electronics almost complete and testing has begun. Pilot line producing 10 panels a day is goal. For more information, contact Al Feddeler, CECOM (201) 544-4926.

Project 3094. Communications Technology Techmod for JTIDS. Contracts awarded to Singer-Kearfoft and Rockwell-Collins to analyze their manufacturing operations to identify areas needing upgrading. Phase 2 will include establishing and demonstrating new capital equipment and techniques. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 9851. Tactical Miniature Crystal Oscillators. Bendix defined braxing, bonding, cleaning, outgassing, and sealing processes for 1 cu. in. TMXO. Vacuum analysis and a crystal temperature slew test station were completed. Test fixture construction has begun. Hybrid circuit fabrication has started. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 9938. Three Color Light Emitting Diode Display Unit. This effort is complete and final report is completed. For more information, contact Al Feddeler, CECOM, (201) 544-4926.

Project 1072. Multiple High Reliability/Low Volume LSI Manufacturing (CAM). Insouth Microsystems is developing processing blocks for manufacturing several circuit types utilizing several technologies. This includes obsolete circuits in isolated junction bipolar, dielectric isolated bipolar, metag gate CMOS and SI-gate CMOS. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1073. Real Time Ultrasonic Imaging. The third program review was held. Although total integration of the prototype had not been completed, much of the system performed well. High quality imagery of flaws in the viper tube was demonstrated. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1076. Automatic Recognition of Chips. Kulick and Soffa Industries is prototyping a small robot and a material handling system and pattern recognition equipment to identify and orient chips, place them on the proper pad on a substrate, and bond them. KES is demonstrating parts to industry. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1088. Optimized Mandrel Fabrication and Utilization For Composite Motor Cases. A second motor case has been hydroburst. The burst pressure was 1740 psig, well above the minimum expected. The program is on hold status awaiting a case insulator from the elastomeric insulation MMT program. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3139. Millimeter Seekers for Terminal Homing (TH). All elements of this contract are complete. Awaiting unclassified version of technical report. A special working group evaluating concept definition proposals for terminally guided warhead received the implementation plan for MLRS-TGW. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3263. Printed Wiring Boards Utilizing Leadless Components. Hughes Fullerton found polyimide/kevlar circuit boards mounted on copper-invar-copper thermal plate best at thermal cycling. 84-lead ceramic chip carriers were vapor phase soldered to the boards. Corner joints were reinforced with rigid epoxy resin. For more information, contact Bobby Austin, MICOM, (205) 876-4197.

Project 3294. Production Processes for Rotary Roll Forming. Technical effort is complete. Final report draft is approved. For more information, contact Bobby Austin, MICOM, (205) 876-4197.

Project 3376. Testing of Electro-Optical Components and Subsystems. All technical work has been accomplished, final technical report draft has been received, modified and approved. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3423. Low Cost/High Performance Carbon-Carbon Nozzles. Concept refinement and reproducibility testing have been completed. For more information,

contact Bobby Austin, MICOM, (205) 876-2147.

Project 3441. Application of High Energy Laser Manufacturing Processes. All work has been completed. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3445. Precision Machining of Optical Components. A major component of the contouring machine tool controller was redesigned and fabricated. The machine was successfully repaired. Additional funds were requested to provide documentation and promote technology transfer. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3449. Alternate Process for IRDI. Program plan reviewed. Literature review completed. Preliminary production plant design and cost estimates started. All required reports prepared and received. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 4575. Laser Welding Techniques for Military Vehicles. Production mock-up using M 1 turret ring casting to inner turret wall completed. Final report film and contract close-out targeted. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5014. Foundry Casting Processes Using Fluid Flow and Thermal Analyses. Contract with the University of Pittsburgh was amended to expand the geometric capabilities of the current procedures. Presentation of program results was made to foundry and tool design representatives for the foundries of Deere and CO and Rock Island arsenals. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5019. Storage Battery Low Maintenance. Prototype batteries from contractor have been delivered to YPG and CRTC for field vehicle tests. Satisfactory performance tests also began. Latter tests very good. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5024. Gear Die Design and Manufacturing Utilizing Computer Technology (CAM). The script for the movie on CAD/CAM of spiral beval gears has been prepared. Shooting is nearing completion. The report is available to all interested parties. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5045. Spall Suppressive Armor for Combat Vehicles (Phase II). An M113 with spall kit loaded with items of personal gear, rations, NBC gear and ammo was fired upon by 2 types of heat ammo. Results showed that the kit performed its function by reducing fragment spray and containing the stowed items. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5053. Fabrication Techniques for High Strength Structural Ceramics. Work to optimize material technology for monolithic ceramic and ceramic coated components. Initial materials passed rupture and toughness tests. AMMRC initiated work on ceramic composites. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5054. Laser Surface Hardened Combat Vehicle Components. Non-surface hardened T-142 and T-156 end connectors and center guides have been purchased. Components are being heat treated. Lab evaluation of laser heat treated components is in progress. Draft final report is being reviewed by the government. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5064. Light Weight Saddle Tank (Phase III). All requested government-owned material forwarded to contractor. Design of tank tooling and fittings finished. Wood mockup of final fuel tank configuration checked for fitting locations and installations. After passing test fuel tanks sent to 4 test sites. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5067. Plastic Battery Box. Final report distributed and validated economic analysis published. Test plan for in-house multi-temperature stress test on M809 box is in progress. Four M39 battery boxes ordered for YPG and installed on the 2.5 ton truck by contractor, AM general. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6350-2205. Holographic Inspection of Rotary Forged Preforms. The design effort for high resolution flow inspection system is 75 percent complete. Prototype electronic cards have been wirewrapped, tested, and debugged. The CVI 200X was recently delivered to RPI. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2225. 3D Shock/Vibration Test for Missile and Artillery Fuze Materials. The project has been successfully completed and a final report is being prepared. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2422. Inspect/Measure Method for Spherical Surfaced Components. The technical work has been completed. A technical report is being published. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2425. Optical Testing of Far Infrared Materials. Interferograms were made on 45 germanium optical blanks. The samples normally were three inches in diameter and one-half inch thick. The samples showed a mean variation in index variation. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2433. Automatic Universal High Voltage Power Supply Test Console. The electronic console has been completed and is being used in the manual mode to test ANVIS, AN/AVS-6 power supplies. The system operating program has been completed and at least 12 of 70 individual test sequences have been completed. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2444. Ultrasonic Testing of Roadwheels. This project has been completed. Distribution of the technical report is under way. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2446. Blacklight Video Inspection System. Additional funds to continue the work were made available. A purchase request for an off-the-shelf video system has been sent to procurement directorate. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2614. Temperature Compensated Voltage Controlled Crystal Oscillator Test Method. Testing for evaluating frequency stability of (TCVCXO) as crystral controlled crystal clocks in the DGM equipment was completed. A draft TR report has been submitted and evaluated. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2628. Standard Contaminant for Test Fuels. This effort has been completed and the final technical report, APG-MT-5759, has been published. This report contains the instructions in the use of polypropylene powders to check the efficiency of fuel filters. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2639. Roadwheel Seal Test Machine. Procurement of required purchase item is in progress. In-house fabrication of the machine is in progress. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2646. Piston Actuator Test. Assembly of the system is complete. The design has been frozen. The system is being calibrated at the present time. After calibration, 100 piston actuators will be tested and the final report written. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-3006. Acoustic Emission Monitoring/Control Straightening. The scope of this project has been expanded. Additional funds for engineering labor and small parts manufacture and acquisition have been requested. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 5071-14. Smoke Obscuration Test Procedures. The investigation has been completed and final report was approved. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-73. Integrated Test Data Acquisition. Three integration test networks employing optical fiber data links have been built. Two of these systems have been bench tested and have had limited field tests. A third prototype is being prepared for test. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-74. Smoke Sampling/Characterization. Tests have been initiated to eliminate the problem of mounted sampler movement on exposure to the explosive shock of the smoke round. Wind tunnel tests for sampling oil, diesel oil and IR obscurant were coordinated. Final report was submitted and approved. For more information, contact John Gehrig, TECOM, (301) 278-2375.

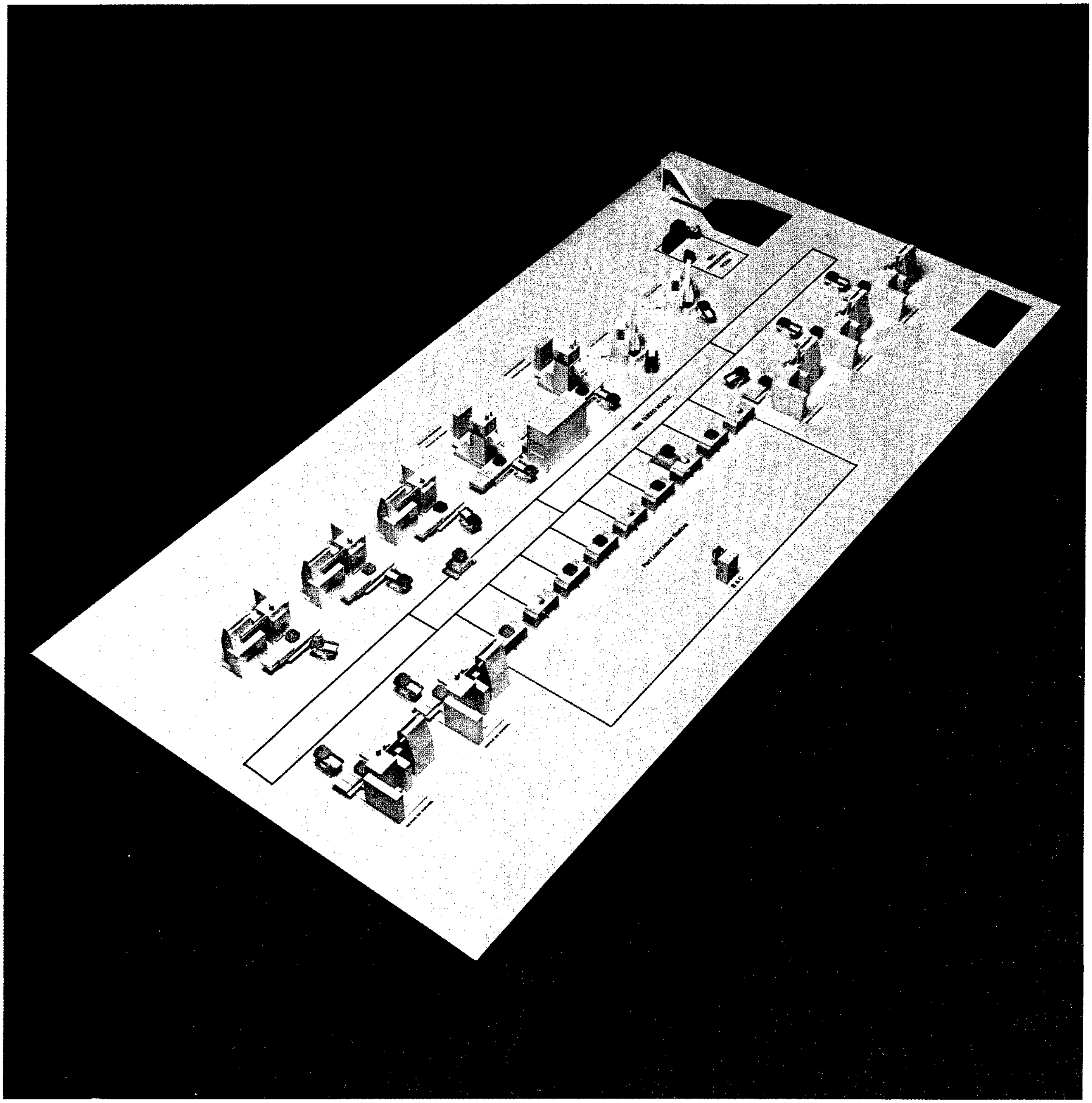
Project 5071-79. Environmental Issues Guide for Humid Tropic Testing. The basic matrix has been developed and coordinated with topographic labs. The program concept for entering and retrieving data is complete. For more information, contact John Gehrig, TECOM, (301) 278-2375.

US Army

ManTech Journal

Retraining the Engineering Pool

Volume 9/Number 3/1984



US Army
ManTech Journal

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Contents

About the Cover:

Flexible Manufacturing System modeled on the front cover will provide automated handling and machining of scores of complex operations required to produce today's large caliber weapons. The system includes machining centers and vertical turret lathes, automatic inspection stations, and robot loading and unloading. Combining several machining operations into one flexible system will enable Watervliet Arsenal to customize all manufacturing operations as needed.

THE MANTECH JOURNAL is prepared quarterly for the U.S. Army under the sponsorship of the Directorate for Manufacturing Technology, DARCOM, by the Army Materials and Mechanics Research Center, Watertown, Massachusetts 02172, through the Metals and Ceramics Information Center, Battelle's Columbus Laboratories, 505 King Avenue, Columbus, Ohio 43201.

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Comments by the Editor

RAYMOND L. FARROW

Hosted by the U.S. Navy in Seattle, the 16th Annual Conference of the Department of Defense Manufacturing Technology Advisory Group (MTAG) will open on November 26 with a record number of attendees expected. The Conference has grown so steadily through the years, it soon will be so large a group that arranging for a suitable meeting place may become a problem. It speaks well of the import that previous attendees place on the past conferences that this attendance continues to grow. The annual conference provides a highly useful forum for industry and service manufacturing personnel to keep up with developments in the defense production base effort.

This year's Conference again features something special and of great interest to those in the manufacturing technology field. On Tuesday, November 27, the Special Topics Day presentations should arouse considerable discourse. The subject's titles in themselves would pique the interest of anyone who is involved with the planning and management of modern-day manufacturing operations. ''The Factory of Today: In Place and In Fact'', ''The Factory of Tomorrow: In Development and Emerging'', The DoD ManTech Program: Three Points of View''; and ''The Industrial Modernization Incentives Program (IMIP): Three Perspectives'' constitute a set of topics that should establish the thrusts of today in defense manufacturing prior to the Mini-Symposia scheduled for the following day of the Conference.

The latter two of the four topics listed above pertain directly to current DoD manufacturing technology programs and will be addressed on Tuesday morning, with the first two topics listed above discussed during the afternoon. There should be some interesting insights developed at these sessions.

A special feature of this issue of the U.S. Army ManTech Journal is an editorial by Fred Michel, Deputy Chief of Staff for the U. S. Army Manufacturing Technology Program at Army Materiel Command Headquarters. Some of the contents of this editorial on training our engineers to handle modern manufacturing operations prove most interesting. The vastness of the Army's production base is signified by the fact that the Materiel Command's fixed assets are greater—even after discounting land holdings—than those of the nation's largest companies, such as Exxon, General Motors, IBM, ITT, and other major oil and chemical firms. The current value of AMC's inventory of materiel is so many times that of any of these large corporations that it's apparent why our engineers face such an enormous challenge. The mantech programs being worked on will help reduce this immense inventory by providing capability to produce—on demand—required military hardware more quickly and efficiently. The training programs discussed for this cadre of engineers/managers represents an important adjunct toward successfully meeting the challenge.

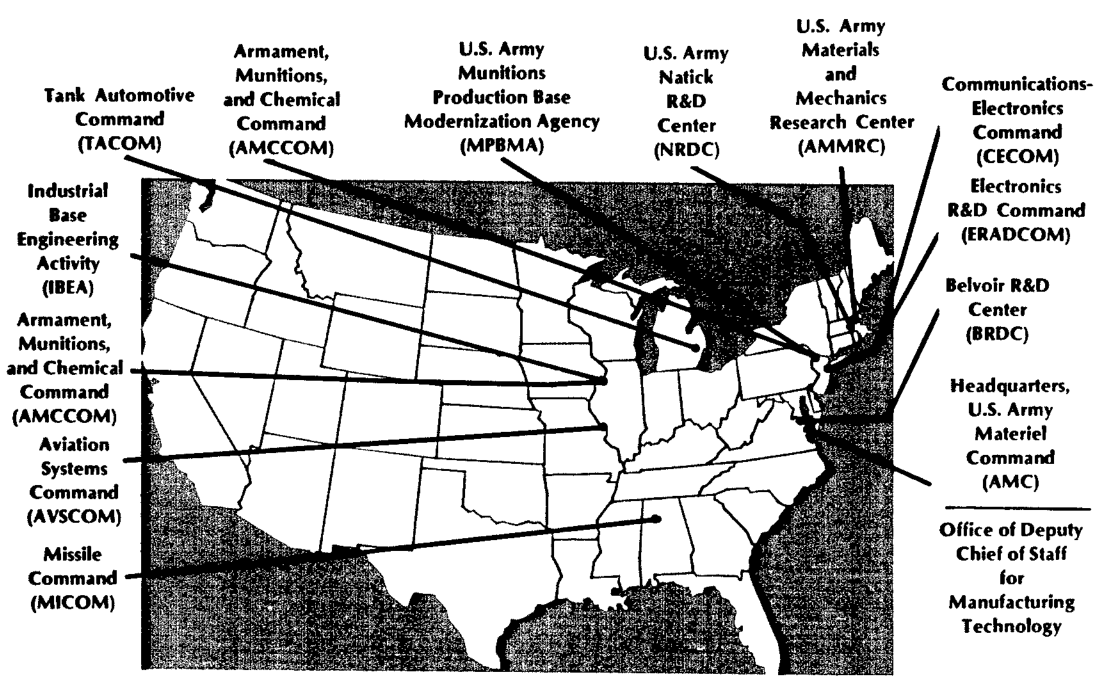
Other highlights of this issue of the Army ManTech Journal include a review of the Project REARM at Watervliet Arsenal and the new Flexible Manufacturing System being installed there. The first of Project REARM's two-pronged effort (an earlier report in this magazine gave an account of the Rock Island Arsenal portion of the effort), the Watervliet Project REARM is nearing its tenth year, going back to the earliest planning. This highly important program will keep our cannon manufacturing capability up to date, implementing the latest technologies.

In addition to a large number of brief status reports of ongoing Army manufacturing projects, this issue of the Journal provides in-depth reports on two very high-technology projects by the Missile Command.

The article on leadless components for printed wiring boards points up one more significant new development resulting from an Army mantech effort—one which will provide greater reliability in our battlefield electronics gear.

The article on the hardening of missile domes reports on a new technique for achieving greater effectiveness in the performance of our missiles. This new ultrahigh technology is described in excellent detail and should prove valuable to our readers.

AMC Manufacturing Methods and Technology Community



Preparing for the New Technologies

Manufacturing Training Underway

FREDERICK J. MICHEL currently is the Deputy Chief of Staff for the U.S. Army Manufacturing Technology Program. This office is responsible for the entire range of Army production engineering programs. He is a member of the Executive Committee of the Department of Defense Manufacturing Technology Advisory Group (MTAG), and until recently held the chairmanship of the CAD/CAM Subcommittee of the MTAG. He also represents the Army at the Manufacturing Studies Board of the National Research Council and is a board member of CASA/SME. Previously, he was employed by the Westinghouse Electric Corporation. He holds a Bachelors Degree in Mechanical Engineering from the City College of New York and a Masters Degree from Columbia University in the same field.

Visualize an employer with over 800 engineers engaged in a manufacturing activity encompassing the widest range of technologies imaginable, and scattered over an area of 2 million square miles. He is charged with the task of producing the materials for a modern military complex supporting the defense of the most diverse nation in the history of the world.

This employer would be ranked first both in inventory and in fixed assets (even excluding land) if he were listed among Fortune magazine's Top 500 firms, and eighth in terms of total sales. The value of his goods is almost twenty-three times that of large retail firms such as Sears or K-Mart.

The employer is facing the stark realization, as are many more organizations heavily engaged in manufacturing such as General Motors, General Electric, etc., that the value of the individual manufacturing engineer as a contributor is decreasing due to the frantic rate of change in manufacturing technology. The rate of obsolescence of skills is purported by those who study such issues to be increasing exponentially because of the widespread introduction of the microprocessor and software systems in manufacturing. The impact has been heightened by the relatively low cost of the microprocessor. This has led to the distributive approach, making it possible to operate the individual manufacturing cell independently from central data processing. Today, electronics is driving the technology on the factory floor.

The employer referred to above is AMC, the U.S. Army Materiel Command. AMC is initiating programs which are designed to accelerate the adaptation of its engineers to those new skills, as are its more specialized commercial manufacturing associates. The median age of the typical AMC engineer is probably somewhere between 45 to 55 years. Twenty-plus years have passed since that person received an engineering degree.

The change is driven by such new technologies as CAD/CAM or CIM, computer control, and robotics. They are the tools which will lead towards the factory of the future. Experienced engineers are both troubled and challenged by all those technologies. They are being adopted at a precipitous rate, as the pressure to lower production costs mounts. Therefore, it is necessary to accelerate the 10-year cycle which has been the norm for adoption of new technology in manufacturing endeavors. Several possible solutions are suggested:

- Formal schooling for special studies or for advanced degrees
- On-site training set up by local schools
- Training seminars
- Training courses offered by professional engineering societies
- On-the-site experience related to new technologies
- Existing AMC training programs.

Activities undertaken by AMC include some new and old programs as exemplified by the following:

1. **Advanced Manufacturing Engineering Studies Program**
A new initiative which offers an engineer the opportunity to undertake a full-time, graduate level program in manufacturing or manufacturing engineering. Typical graduate school requirements will involve 18 months to complete the course work and projects. All expenses are paid by the Army including full tuition, compensation, and health benefits. An increasing number of institutions across the country have established graduate level engineering programs with a concentration in manufacturing and production. The first AMC engineer on this program started at the Massachusetts Institute of Technology in September, 1984.

2. **Manufacturing Training With Industry (MTWI)**
A new initiative designed for engineers to gain direct experience in manufacturing. Civilian production engineers in AMC are selected for 1-year working assignments with industry. These engineers are given "hands on" manufacturing engineering assignments. Consequently, the AMC engineer is required to make a technical contribution to the manufacturing operation of the host firm. This precludes "observational" type assignments. As a result, the AMC engineer will acquire a first-hand appreciation of the effect of his effort on cost. At this writing, AMC engineers are working at Martin-Marietta and the John Deere Company. The program will be expanded as new nominees are approved.

3. **A Career Intern Program for Engineering and Pre-Engineering**
An existing AMC entry level engineering training program that will provide a participant the opportunity to complete the requirements for a Master of Science degree in manufacturing engineering. The courses are taught at the Red River Intern Training Center of AMC. Several universities are being considered to then provide additional courses, the combination of which with the Red River training will qualify the student for the advanced degree.

Gone forever are the days when a young engineer can enter the manufacturing arena and be certain of a comfortable, unchanging, lifelong career in engineering. Never again will acquired engineering competence alone offer a sure path to job security and ultimate retirement. Adaptation to change and continual development of new skills to handle new technologies will forevermore be the way of life for the Army engineer.

We at AMC plan to continue investing heavily in the establishment of long-term development programs for our engineers to carry them into the next century.

Old Blended With the New

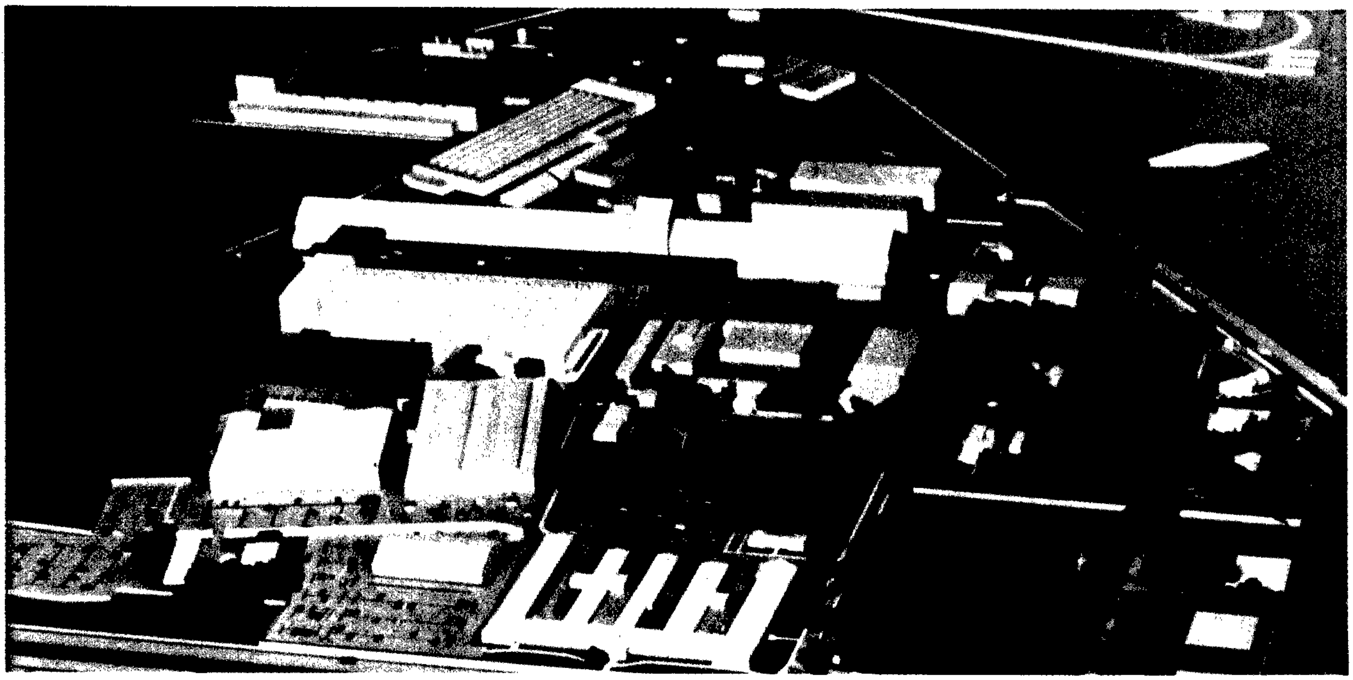
Watervliet Arsenal— Past, Present, and Future

NOTE: The following article was prepared by staff of the U. S. Army ManTech Journal from materials provided by John E. Swantek, Public Affairs Officer at Watervliet Arsenal, Watervliet, New York.

Watervliet Arsenal has been producing cannon—large caliber weapons—for nearly 100 years. It has been producing ordnance material for more than 170 years.

Uneasy peace filled the years following the successful conclusion of the Revolutionary War. The long struggle among the great powers of Europe for mastery of the continent had created an instability in world affairs which more than once threatened to draw the young United States into the vortex. Attempts to keep America from becoming involved had failed and a series of incidents at home and abroad carried America at last to the threshold of war in the twelfth year of the new century. On June 18, 1812, Congress voted for war against England, in accordance with the President's recommendation. He had cited England's impressment of American seamen, violation of United States territorial waters and restraint of American trade. Congress had agreed: the country's only hope for redress of these wrongs lay in a resort to arms. The following day president Madison proclaimed the war, charging England "with a course of conduct insulting to the independence and neutrality of the U.S." Thus, the young nation which once had fought to gain freedom and rights was again at war to preserve them. Yet, England was a most powerful nation with large, veteran armed forces on land and sea, while the United States military establishment was almost non-existent by comparison. The extent of the American wilderness frontier and seaboard was enormous and the army would have to be much increased to defend it. The task of arming these troops and providing their materiel support over these vast areas was given to the United States Army Ordnance Department, then a little more than one month old. The Ordnance Department selected one Arsenal to be located somewhere in upper New York State, so that materiel could be sent either north or west with the greatest speed, as the Americans expected to be attacked from the north at Lake Champlain and from the west at Niagara Falls. In the Village of Gibbonsville, which the Old Dutch settlers had called "Winter's Plantation," a very suitable plot was discovered. If the British struck at Lake Champlain, a portage of only sixty miles to the lake from the Hudson River would be necessary. If the enemy came from Lake Ontario, supplies could be shipped up the Mohawk River, and if New York were

NOTE: This manufacturing technology project that is being conducted by Watervliet Arsenal was funded by the U.S. Army Armament Munitions and Chemical Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The Watervliet Point of Contact for more information is Mr. Gary Conlon, (518) 266-5737.



ARCHITECT's MODEL of Watervliet Arsenal after the completion of Project REARM shows the three main production buildings being added (dark colored.) Other buildings have been razed and the end result will be an integrated, thoroughly modern production plant capable of manufacturing high quality products for America right into the 21st century.

attacked, the Hudson furnished a means of quick shipment to the south. This was the perfect site.

Since then, there have been many changes. The Civil War and War with Spain. World War I. World War II. Korea. Vietnam. All brought challenges to Watervliet. New weapons were developed. New processes were needed to produce these weapons more effectively. Watervliet Arsenal has stayed in the forefront of cannon production.

Now, the Arsenal is undergoing the most comprehensive change in its history, through Project REARM (Renovation of Armament Manufacturing). This $250 million project will revamp the Arsenal's cannon manufacturing capabilities. Three major new production buildings and hundreds of new, up-to-the-minute manufacturing machines are changing the face of the Arsenal.

The problems facing Watervliet were common to many plants throughout the country: to take yesterday's factories and turn them into tomorrow's factories. Many of today's factories—particularly those located in America's industrial heartland, the upper midwest—have several things in common.

They have a lot of floor space in relation to annual production. They are old.

The equipment is outmoded.

In-process inventory is very high. There is probably more than 33 cents in total inventory for every dollar of sales. The inventory turn doesn't exceed 3 to 3½ times.

These operations cannot compete effectively with newer plants.

Project REARM Initiated

Preliminary work for Project REARM had begun in 1974 when Arsenal officials, well aware of the strain placed on manufacturing equipment and buildings by the demands of production for the Vietnam conflict—a problem made more serious by the fact that much of the manufacturing equipment dated back to the Korean War or even World War II—commissioned the Detroit, Michigan, engineering firm of Giffels Associates to conduct a thorough study of the cannon production base and the Arsenal's manufacturing functions and to make recommendations concerning the modernization of these facilities. This was to be done with a view to bringing all of these up to the state-of-the-art in order to increase production flexibility and provide an increased ability to respond to the demands of a national emergency.

The Giffels study, presented in June, 1975, concluded that considerable savings could be made by a realighment of plant equipment packages according to caliber rather than by individual weapons. Thus, plant equipment packages would be set up to deal with 155 mm weapons within that category for which mobilization responsi-

bility was assigned. Further, the studies indicated that lead times could be shortened and economies achieved by retaining the manufacture of all thick-walled cannon for peacetime, war reserve and mobilization at Watervliet Arsenal and procuring all thin-walled weapons—mortars and recoilless rifles—from other sources. Central to the savings possible through these recommendations would be the modernization of the buildings and equipment necessary to carry them out.

The first result of the Giffels study was an Arsenal military construction project to build two new manufacturing buildings and a new oil storage facility and to renovate several other buildings. Included was the demolition of several older buildings necessary to make way for the new construction. Plans were submitted also for the rehabilitation or replacement of 680 pieces of manufacturing equipment. Officials also hoped to acquire a large number of programmable numerical control machines.

The total Project REARM included requirements for both buildings and equipment. Construction was programmed in fiscal year 1979 that would involve demolition of some 19 obsolete buildings—many of them temporary wooden buildings of World War II vintage, construction of two major new manufacturing buildings, and an oil storage facility and renovations to six buildings.

For the Arsenal, fiscal year 1978 was pivotal for project REARM. While negotiations were going on during the first quarter between Lev Zetlin/Giffels, Inc., and the New York District Corps of Engineers to initiate design of the proposed buildings, the construction funds in the budget began to flounder.

Although the projct originally enjoyed a very high priority, a cutback in the Department of Defense budget resulted in the development of a new priority listing for all Department of Army and Department of Defense project requests. The Arsenal's modernization program came up during these discussions because contract award for Phases I and II of construction were scheduled for late in the fiscal year.

The final resolution came in mid-December, 1977, when Secretary of Defense Harold Brown briefed President Jimmy Carter and received guidance to prepare a $126 billion defense budget. This resulted in the budget approval line being drawn just above the Watervliet Arsenal project. Deferring the funding to FY80 could have resulted in a delay of up to one year in occupancy of the first new building, as well as inflated project costs and deferred accrual of projected savings.

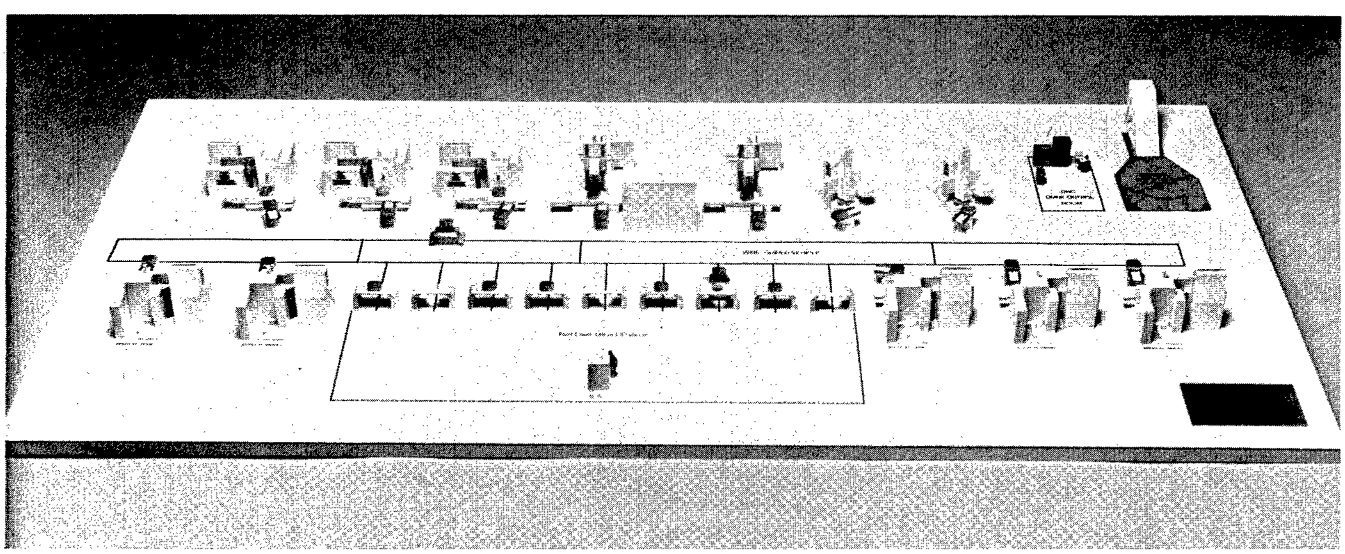
The $20.5 million for demolition and new construction was for the first year of a five-year building plan. The major demolitions would be made to Buildings 105 and 14, 19th century structures housing offices and small shop facilities; Building 30, the carpenter shop; the heat treat wing of Building 110; and a portion of Building 108 containing offices. Also scheduled for demolition were several small utility buildings.

The two major new manufacturing buildings would be added to existing Building 35. The west addition would be 110,000 square feet in size and would house facilities for medium caliber gun tube manufacturing. On the east side, 67,000 square feet would be added for heat treating, platting and supply operations. Construction would also include a new building for storage of petroleum, oil and lubricants, as well as renovations to six existing buildings.

Heritage Preserved

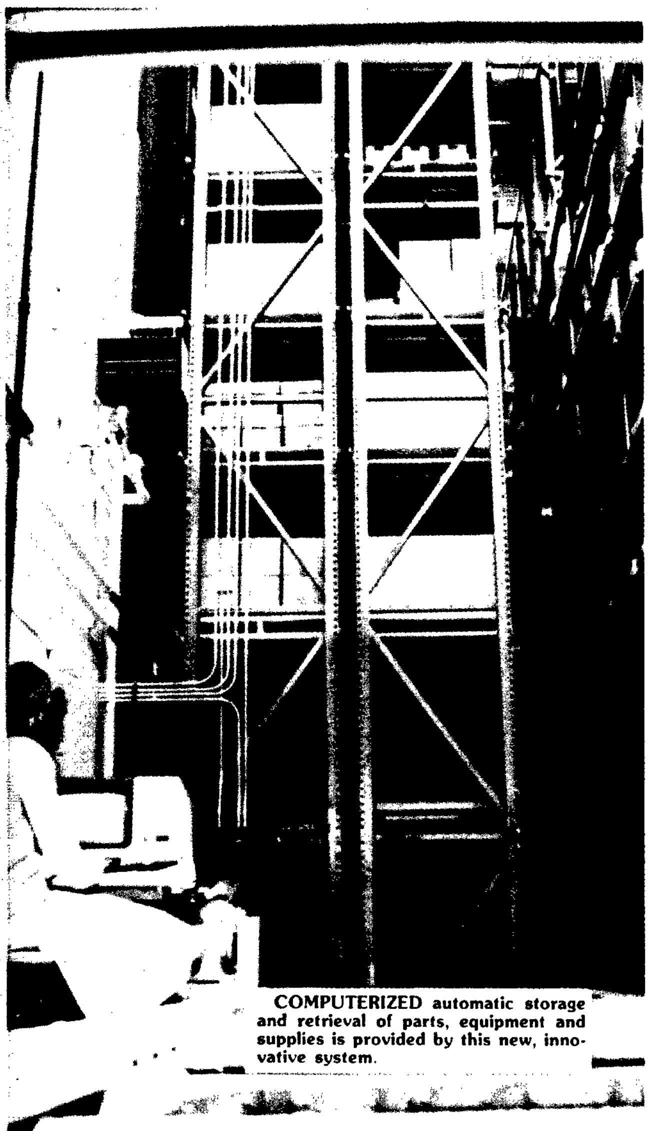
Because the Arsenal had been a Registered National Historic Landmark since 1966, the REARM demolition and construction plan required the concurrence of both the New York State Historic Preservation Officer and the Presiden's Advisory Council on Historic Preservation. To obtain these concurrences, the Arsenal prepared and submitted extensive documents detailing the impact, alternatives and mitigative measures that would be taken to preserve the historic nature of the Arsenal. These documents were fully coordinated with the New York State Historic Preservation Act of 1966 and other federal and state laws. This action was pioneer for the Department of the Army. The Arsenal's agreement represented the first ever concluded between a military installation and federal and state preservation officials. As such, it was touted as a model and precedent that would be followed and consulted by other military installations in the future.

Also approved in the fiscal year 1979 defense budget was $13.5 million for new and rehabilitated machines. This



marked the first installment of some $130 million for equipment that would be requested over a six-year period. REARM included plans for buying and rehabilitating several hundred machines. These included lathes, milling machines, grinders, threaders, broaches, presses and boring machines.

In May 1978, a master plan for Project REARM was published and distributed throughout the Department of the Army. The plan was based on 1982 mobilization requirements that related cannon and spare tube production to planned force structure and ammunition consumption rates. This plan established courses of actions needed to meet requirements based on economics, responsiveness, and the capabilities of both commercial and government facilities. In developing the plan, priority was directed toward those modernization efforts required to support planned peacetime procurement of tank guns and artillery.



COMPUTERIZED automatic storage and retrieval of parts, equipment and supplies is provided by this new, innovative system.

One of the most important components of the master plan was the equipment upgrading requirements. The results of the equipment condition assessment completed earlier were reviewed by Booz-Allen Applied Research, Bethesda, Md. In their final report, furnished in February 1978, Booz-Allen found that the criteria used by the Arsenal in determining equipment conditions were comprehensive and that the data supporting the priorities and budget estimates was accurate. Booz-Allen concluded that "there is substantial evidence for a large program to restore lost capability and to compensate for continuing wear and tear on at least 420 machines." To meet future peacetime production requirements and to provide a responsive and reliable emergency production capability at Watervliet Arsenal, the assessment showed the need for investments of more than $130 million for the purchase of 492 pieces of equipment and rehabilitation of 188 machines. The project requests for this effort were submitted in the Department of the Army's Production Base Support Program in January 1978, along with a strong Manufacturing Methods and Technology (MMT) program needed to insure that goals would be met.

In a fanfare marked by ruffles and flourishes, speeches by Army and Congressional dignitaries, and the climactic crash of a wrecking ball into Building 105, Project REARM got underway with a highly successful ground breaking ceremony on March 30, 1979.

Computer Aids, Robotics

Most of the new equipment obtained through Project REARM indeed is computerized. As computers become more a part of our daily home life, they are also becoming a integral part of the work life at Watervliet. Terms such as "computer-numerically-controlled," "computer-aided design" and "computer-aided manufacture" are commonplace. Even robots, once linked exclusively to science fiction movies, are being put to constructive work at the Arsenal. Modern industrial robots, however, look nothing like the human-shaped machines of the movies. Robotics in manufacturing usually means a system of levers and clamps which are controlled by a computer and perform complex movements within a manufacturing system.

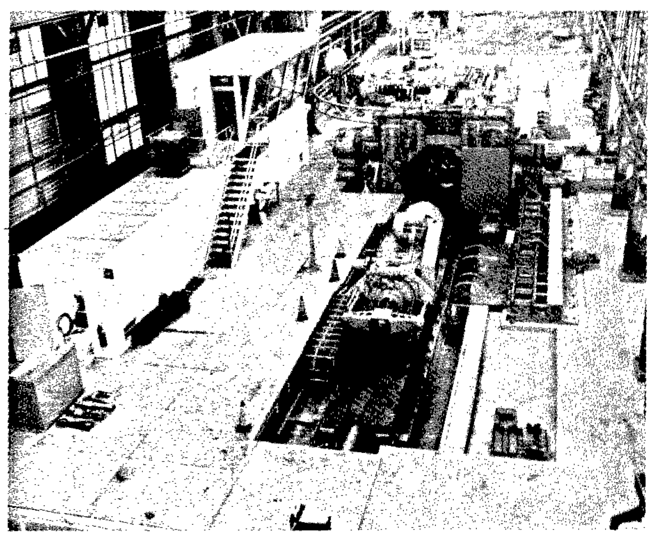
Flexible Manufacturing System

Typical of the state-of-the-art equipment being installed is a Flexible Manufacturing System. This massive manufacturing center—which is the largest single purchase ever made by the Arsenal—will automate several major operations in the manufacture of cannon components. The system includes machining centers and vertical turret lathes, automatic inspection stations, a washing station and a load-unload area where parts will be taken out of the system on pallets.

Scores of complex machining operations must be accomplished in the manufacture of today's large caliber weapons. Combining several machines into one flexible system will allow Arsenal operators to virtually customize manufacturing operations as needed.

Another futuristic addition to the Arsenal is the Automated Storage and Retrieval System, already in operation. This computerized system allows for the storage of supplies, components, parts and other items in high, vertical stacking bins. Items are stored and retrieved automatically by computer-directed cranes. An operator at a computer terminal tells the cranes where to store pallets. And, by pushing a few buttons, the pallets will be retreived automatically. This vertical storage makes the most efficient use of Arsenal storage sapce.

Computers will also become part of the daily routine outside the manufacturing areas. The number of computer terminals will increase as much as ten-fold in the next few years. The plan is for "data cells" to be set up within each of the Arsenal's major organizations. Computer programmers will be trained to produce software geared specifically to the needs of these individual Arsenal units. In addition, many Arsenal employees will be able to make use of these computer terminals in the course of their daily work without a great deal of technical training. Massive amounts of paperwork can be eliminated (along with the need to store this paperwork).



The Operations Directorate is the manufacturing element of Watervliet Arsenal. It is in Operations that a cylinder of steel is turned into a precise, well engineered, state-of-the-art large caliber gun tube.

A gun tube must be made of special alloy steel. It must be absolutely straight. Machining must be accomplished to fractions of an inch.

The Arsenal also manufactures the breech mechanisms for these gun tubes. This is the device at the loading end of the tube. Many parts must be machined to fit together to close tolerances.

It is the responsibility of the Operations Directorate to take the rough steel "preforms" and turn them into the finest large caliber weapons to be found anywhere.

The Operations Directorate is made up of four divisions: Manufacturing, Production Planning and Control, Quality Control and Supply.

The Manufacturing Division, of course, is responsible for the "hands on" work of manufacturing the finished product. Some of the special processes involved are mentioned below.

Production Planning and Control is responsible for planning, organizing, directing and controlling the production. This involves the use of modern management and engineering techniques to insure that Operations meets all of its contractual obligations and does so with the greatest possible efficiency and productivity. It is here that managers and engineers work to improve the processes and integrated systems of labor, material and equipment to produce the best product, on time and at the right price.

Quality Control aims at insuring that the finished product is of the highest quality. Through the efforts of this division, cost reductions are achieved by preventing defects in the manufacturing process.

Supply Division provides an important staff function. Here, supplies and equipment are warehoused and distributed not only within Operations but throughout the Arsenal.

The "big guns" produced at Watervliet are generally recognized as among the finest in the world. This is no accident. This quality is maintained through constant research and development, and new management and manufacturing techniques.

Revolutionary Technology

One of the most interesting new manufacturing developments is the use of rotary forge technology. This has revolutionized the manufacture of thick-walled cannon. The rotary forge, installed in 1975 at a cost of $14 million (and the largest of its kind in the world), can produce a gun tube forging in 10 minutes where it once took four-and-one-half hours!

A computer-assisted forge, using four massive hammers, pounds out the rough shape of a gun tube. The hammers, automatically controlled, develop a force of 1,100 tons, pressing 200 times per minute.

But the forging process only provides the rough shape of a tube. Many other important processes must be applied. The bore (inside the gun tube) must be chrome plated. The tube must go through a process called autofrettage, where, by means of a special process, the tube is made many times stronger. Machining makes the tube ready to receive the various component parts such as the breech mechanism and, if the particular gun calls for it, the muzzle brake. Both of these are also manufactured at the Arsenal.

Each of these processes has been developed and continually improved over the years. Even the special wooden

crates in which the guns are shipped are made at Watervliet.

In accomplishing these tasks, Operations Directorate makes use of the latest technological devices and processes. Black light and laser technologies are used to examine the work done on the guns. Numerically controlled machine tools are used. An automated plating facility makes that job more efficient.

FMS Buy Unique

In a landmark REARM procurement action, Watervliet Arsenal awarded a contract to The Manufacturing Systems Division of White Consolidated Industries of Belvidere, Illinois, for a $15.3 million flexible manufacturing system (FMS) which will automate several major operations on major cannon components here.

It is the largest single dollar-value procurement ever carried out by Watervliet Arsenal; the unique action took more than three years to complete.

The flexible manufacturing system will provide the Arsenal with an integrated computerized facility able to perform more than 50 percent of the major operations on breech blocks and breech rings for 105 mm, 120 mm and 155 mm weapons.

The FMS will be composed of major machine tools plus other state-of-the-art pieces of equipment, numerically controlled, of proven reliability and efficiency.

There will be machining centers and vertical turret lathes plus automated inspection stations, a washing unit and the associated load-unload area where parts will be put into and taken out of the system on pallets.

Within the system they will be moved from station to station on trolleys running along wired tracks in the floor which will direct them by magnetic impulses sent out by the command computer. The computer will also select the machine required for the necessary operation and give it its orders.

The Arsenal will have a system in between the transfer system production line you would see in a Detroit car plant where rows of identical machines perform identical operations on thousands of identical pieces, and a job-shop operation where a large variety of 'standup' machines perform a large variety of operations on relatively small numbers of pieces.

The flex complex will be a mid-volume system which will provide many of the advantages of both of the other systems and will suit very well the types and volumes of work which the Arsenal is called on, either in peacetime or mobilization.

Building 35 is the site at which the FMS will be installed, and the schedule calls for going into rapid action on preparations, with final acceptance for operation in April-May 1985.

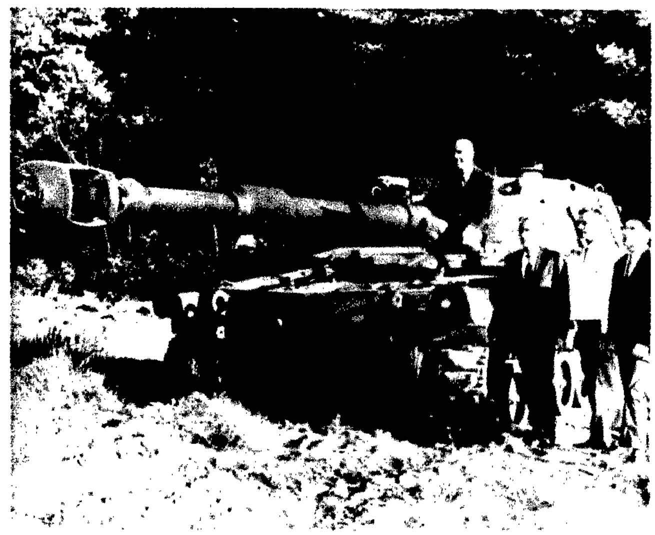
The Arsenal expects to amortize the $15 million investment, or achieve 'payback', in about five years at peacetime production rates.

And 'payback' was the magic word in the unique, difficult, and eventually highly successful procurement procedure.

Instead of the normal low-bidder situation that has sometimes presented difficulties in government acquisitions, as a result of procedures worked out by Arsenal staff, a three-level system was used:

- The bidding was opened to all possible suppliers in the world;
- Three corporations, all American, were selected for the second screening;
- From these, The Manufacturing Systems Div. of WCI was eventually selected.

Instead of the normal low 'responsive and responsible', the selection was based on a complex matrix with points given for price, technical requirements, and 'payback' time.



The three companies finally considered were provided with virtually the whole technical data package for the components required and allowed to produce their own designs for performing the work.

After considerable lengthly negotiations over details, The Manufacturing Systems Div. of WCI was chosen as the best provider for the system the Arsenal needed, even though the company was not the low bidder.

The final agreement was for a system at a cost of $15.3 million, with equipment delivery to begin in 390 days and be complete in 800 days and a shortest-time payback of two years.

After eight months of preliminary planning, the procurement action began in September, 1979, with a pre-procurement conference between representatives of Procurement, Operations, Benet Laboratory, Management Information Systems Directorate, and advisors who continued to work in close cooperation until the completion of the action.

A bonus of the award was that the work on the FMS is being done by American subsidiaries of the parent com-

pany and is expected to benefit economically depressed areas in Illinois and Connecticut where they are located.

Oldest Continuously Active Arsenal

Watervliet Arsenal today is the oldest continuously active arsenal in the country. It is also among the largest, most modern and efficient large caliber weapons plants in the world. The Arsenal is the principle source for such weapons for the United States and many of our allies.

The 10 buildings on 12 acres of land which made up the original arsenal have grown into 91 buildings on 150 acres with more than two million square feet of floor space. About 2,600 people make up the ''Arsenal Family'' including the Arsenal proper and tenant commands such as the research and development facility, property disposal office (surplus) and communications center.

Watervliet Arsenal is the second largest industrial employer in the Capital District of New York. Located in Watervliet, a city of 11,300, and only six miles from the state capital at Albany, the Arsenal is in the heart of the northeast industrial corridor. There is abundant transportation, skilled labor and easy access to the country's major population centers.

Watervliet Arsenal is part of the U.S. Army's Armament Munitions and Chemical Command. AMCCOM is, in turn, a major subordinate command of the Army's Material Command—AMC. AMC consists of a nationwide netowrk of installations and subinstallations which is charged with the major task of keeping America's troops properly supplied with the best equipment and material. This means not only purchasing and supplying but researching, developing and manufacturing material needed by today's modern Army.

Watervliet Arsenal operates much like any other business. As part of the Army Industrial Fund, the Arsenal must be virtually self-sustaining. An initial capital investment was made to start the facility and now the Arsenal must produce a quality produce which can be sold at a competitive price and cover costs of manufacturing and other plant-related operating costs—just like any other major industrial facility.

In the case of the Arsenal, this initial investment of taxpayers' money has been a good one. The value of the original investment is estimated at $195.8 million. The replacement value is approximately $801 million.

Organization a Key Factor

Today's Arsenal is organized into several major departments called directorates with the heads of these directorates reporting directly to the commanding officer. (The Arsenal has always been commanded by an active duty Army officer, usually a colonel.) The largest operating unit is the Operations Directorate, which is responsible for manufacturing and direct production work. The Procurement Directorate takes care of orders for large caliber weapons and is responsible for value engineering, industrial readiness and mobilization efforts. The Product Assurance Directorate makes sure of the quality of cannon produced at Watervliet.

Ohter major organizational elements include: the Comptroller's Office, Civilian Personnel Office, Management Information Systems Directorate and Facilities Engineering Directorate (which is responsible for the physical plant.) The Benet Weapons Laboratory, a tenant command, is made up of more than 300 people engaged in research and development of processes and designs for large caliber weapons systems.

BENET WEAPONS LABORATORY's investment casting foundry is a unique facility. Here skilled craftspeople produce castings of small parts that would be impractical or impossible to purchase and intricately-shaped objects that would be too expensive to carve out of solid steel Steel flows like water, in photo above, as molds are filled. Some of the steel "trees" or castings still connected by steel limbs are shown below.

The Basic Mission

The basic mission, the reason for the Arsenal's exisence, is to manufacture quality cannon and the speciall tools, test equipment and training devices needed to support modern large caliber weapons. For 100 years, quality cannon from Watervliet have been used on tanks, mortars, howitzers and recoilless rifles.

Watervliet Arsenal, through the Procurement Directorate, has the national cannon procurement mission. This means that, in addition to manufacturing cannon, the arsenal is the purchasing agent for the U.S. Armed FOrces for such large caliber weapons systems. Orders from branches of the Armed Services and U.S. allies are placed through Procurement.

The third major element of the Arsenal's mission is mobilization and industrial readiness. In the event of a national emergency, Watervliet Arsenal has to be prepared to meet an increased demand for its product. It also is responsible for providing designated private industrial firms with the equipment and know-how needed to produce increased numbers of cannon to meet the mobilization demand.

It is somewhat unusual for an installation of Watervliet Arsenal's size to be charged with such a national mission but the historical expertise and concentration on one principle product—cannon—has prepared the Arsenal staff for the challenge.

The process of meeting the mission begins with the Procurement Directorate, an Army term for what would be the purchasing office in private firms. The Procurement Directorate purchases cannon for the U.S. forces. Orders are received and placed in-house with the manufacturing division. Procurement also receives orders for cannon from foreign governments—allies of the United States—through federal offices in Washington, D.C.

The Procurement Directorate also purchases all materials used in manufacturing, supplies, plant equipment (especially important as new, modern equipment replaces the old machinery) construction contracting services and the like.

In addition to contracting for the best value for every dollar in purchasing, Procurement also conducts a Value Engineering Program which attempts to save the government money by engineering cost-saving features in Arsenal products and procedures.

Mobilization Procedure

A major responsibility of the Procurement Directorate is planning for mobilization. Cannon needs during a national emergency are determined and then Procurement determines how that demand will be met. The Arsenal, operating at peak capacity, cannot meet the total estimated demand, so Procurement must line up private industrial firms willing to take on the manufacture of cannon during an emergency.

Overall, Procurement makes annual purchases totaling \$50 million. About half of that amount goes for the purchase of forgings for cannon tubes and other major components. Minor components used in manufacturing account for another 15 percent. General supplies and materials make up about nine percent. The remainder goes to pay for everything from construction and new plant equipment to water and electricity.

From Procurement, an order goes to the Operations Directorate, where the actual product is produced in the Arsenal's modern plant.

Products

Watervliet Arsenal is the nation's cannon factory. As such, the Arsenal is equipped to produce cannon with bore diameters from 20 mm (less than one inch) up to the massive 16 inch guns of battleship fame. At one time or another, the Arsenal has manufactured just about every size cannon in between.

The current mission is to produce cannong used on self-propelled and towed artillery and on the tanks of our Armed Forces. Among the principal products manufactured at the Arsenal are:

- 40 mm Gun
- 60 mm Lightweight Company Mortar
- 4.2 inch Mortar
- 81 mm Mortar
- 105 mm Gun for the M60 Tank
- 105 mm Howitzer
- 120 mm for the new M1 Tank
- 155 mm for Howitzers
- 165 mm Gun
- 8 inch Howitzer.

In addition to these basic gun tubes, the Arsenal manufacturers the various base plates and mounts for the mortars and the breech mechanisms and tube assemblies for the large weapons systems.

Many of these large caliber weapons have been designed by the Benet Weapons Laboratory and are produced only at Watervliet.

The 60 mm Lightweight Company Mortar is a prime example of the close cooperation between the research-development and production elements. This modern weapon in general use by the Army can be fired from a baseplate on the ground or can be hand held. It weighs much less than previous company mortar systems—only 18 pounds in the hand held mode.

The largest of the weapons currently in production is the 8 inch howitzer. This gun is used on the M201 self-propelled howitzer system.

Among the newest of Watervliet's products is the 120 mm gun for the M1 Abram tank, the Army's new main battlefield tank. The prototype guns were manufactured at Watervliet and the actual production models are now coming off the line.

The largest guns ever built by Watervliet are the massive 16 inch bore diameter guns last used on Navy battleships. These guns weight more than 100 tons and measure up to 70 feet in length. Their accuracy and range are well known. They are capable of firing a projectile weighing 2,000 pounds over a range of more than 20 miles.

The battleship version, however, was not the first. During the Spanish-American War, the Arsenal produced 16 inch guns called Seacoast Cannon. These were designed and built to line America's coastline to protect against attack by enemy ships. (The Arsenal's "Big Gun Shop" was once called the "Seacoast Cannon Shop.")

The cannon produced by Watervliet Arsenal are purchased by the Army, Navy and Marines. Through special arrangements made by the federal government, cannon are also sold to foreign countries—allies of the United States.

Several other countries are equipped to manufacture thick-walled cannon and Watervliet must compete with them. This means that the product must be produced at the right price and, most importantly, it must be of the finest quality.

Research and Development

Research and development have played a strong role in the success of Watervliet Arsenal. Innovation and new technologies have been sought as a means for producing new and better products at lower cost.

This history of research and development was formalized in 1962 with the dedication of Building 40 as the Benet Research and Engineering Laboratories, known simply as Benet Weapons Lab. Several years later, two additional buildings were equipped to house scientists and engineers as the program expanded.

The research and development facility is named in honor of two men who played major roles in the development of Army ordnance and are closely tied to the Arsenal's history. Brigadier General S. V. Benet had served for 17 years as chief of Army ordnance. His son, Col. J. Walker Benet was commanding officer of Watervliet Arsenal from 1919 to 1921. Col. Benet's sons, Stephen Vincent and William Rose, became two of America's finest authors. In fact, Stephen Vincent Benet wrote part of his first book while living in Arsenal quarters.

Benet Weapons Laboratory conducts research, testing and extensive prototype production of large caliber weapons. The scientists and engineers of Benet focus on the study of materials, mechanics, mathematics and metallurgy. Their research and development facilities have access to the free world's bank of scientific literature in all major disciplines through a link up with the Army's most advanced computer system.

There are three divisions: Research, Development, and Processes. The Research unit develops new knowledge about weapons and the materials used to build them. The Development division designs advanced weapons systems from concept to proven design. It also provides the technical data and documentation needed to make these weapons ready for production. The Processes unit develops special machines and equipment to reduce costs, improve the quality and increase the productivity of weapons manufacture.

Benet Weapons Laboratory has some of the finest scientists and engineers to be found in any research and development facility. More than a third have advanced degrees. The three principle disciplines are mechancal and general engineering, mathematics and metallurgy-materials engineering.

The mechanical and general engineers design hardware, develop and test new guns, mounts, loaders, and recoil and breech mechanisms, also metallurgical techniques and new manufacturing processes. Mathematicians analyze models and simulations of weapons dynamics and stress analysis.

Benet research and development involves not only practical development of new weapons and processes but pure research into the properties of metals which may have applications in many other industrial and research areas. Many papers are published by Benet's staff and they are sought for participation in national and international conferences and symposiums.

The Benet scientists and engineers are involved in the age-old quest of cannonmakers—finding the maximum strength to weight ratio. The object is to build the strongest gun at the lightest weight. Soon after the dedication of the Benet building, a finding was announced which was a portent of the quality of research to follow.

"Whiskers" were used for the first time on an experimental basis. These "whiskers" are tiny crystals of various metals which are "grown" in high temperature furnaces and used to strengthen cannon-making materials. This works much like the reinforcing rods used in concrete building construction.

In 1967, a process for anodizing the surface of titanium components and, later, for successfully coating titanium with an energy-absorbent material was put to immediate use in helicopter construction.

One of the main achievements of the Benet staff has been the successful use of a process called autofrettage. Failures of some 175 mm guns in Vietname had caused the Army to reduce the safe firing life of these guns from 1,200 rounds to 300. This put great pressure on the Arsenal to produce four times as many guns at great expense. Benet researchers were able to apply the autofrettage process of prestressing the walls of the cannon barrel, which restored the 1,200-round lifespan. First year savings wer estimated at $21 million and an equal amount was saved over the next 10 years.

Benet scientists and engineers have been honored 10 times with the Army Research and Development Award—the highest Army research honor. In 1969, three researchers were given the award for their work on the theory of the mechanics of solids. In 1971, five Benet people won the award for their investigation of fracture mechanics problems in thick walled cylinders.

Guided Boring, Simulated Firing

Toward the end of the Vietnam conflict, one Benet scientist was credited with the "most significant new process to be introduced into gun-making in three decades." This was the development of a guided boring system. Boring and cutting tools were successfully married for the first time to electronic sensors. This meant that a bore hole could be cut lengthwise through a 36-foot long forging of super hard steel with a deviation in straightness of less than five-thousandths of an inch—the thickness of a razor blade.

Another dollar-saving process came out of Benet in the mid-1970s. The replication of the high pressure conditions present in a cannon tube when it is fired made it possible to test gun tubes without actually having to fire them. In the first three years of use, this high-pressure testing saved the Army more than $90 million. The process was later adopted by the British and German governments. And Benet earned yet another Achievement Award.

As the new decade of the 1980s dawned, Benet was honored again with the Army Research and Development Achievement Award. This time for the development of the 60 mm Lightweight Company Mortar system. The new system has the same range as the old 81 mm mortar, but it weighs only 45 pounds fully mounted, or less than 18 pounds in a hand-held mode.

Benet Weapons Laboratory continues to explore innovative ways to produce better weapons for the security of America while finding ways to reduce costs and discovering new scientific frontiers.

Most Important Asset

All of this modern equipment is useless unless people are trained to put it to good use. The Arsenal has one of the largest, most specialized pools of armament talent. Generations of local families have learned their skills and plied their expertise at the Arsenal. The Arsenal's Apprentice Training Program has been training machinists and other trades people for more than 75 years—the oldest continuously active apprentice school in the nation. Apprentices are put through their paces in rigorous four-year program which includes classroom work in math, science and related subjects as well as on-the-job training in Operations shops.

It has been said that the real "big guns" of Watervliet are its people. Nowhere is this more true than within the Operations Directorate.

The resultant combination of new facilities, new equipment and new skills for people will keep Watervliet at the forefront of manufacturers of large caliber weapons. This combiantion of resources also means the Arsenal can face the future with confidence. If future ordnance developments mean that traditioinal cannon are replaced by some new weapon, the resources of Watervliet Arsenal will be ready. Just as the Arsenal made the transition from making horse harnesses during the civil War to producing the big guns for World War I, so, too, will it be ready for a future transition.

For the foreseeable future, however, Watervliet Arsenal will continue to produce the finest large caliber weapons in the world—on time, safely and efficiently.

Historic Landmark

The entire Watervliet Arsenal is on the National Register of Historic Landmarks. Not just a building or two but the entire 150 acre installation. This is in recognition of the historic value of the Arsenal facilities, but it also is a tribute to the continuous development and present-day value of the Arsenal as a large caliber weapons production facility.

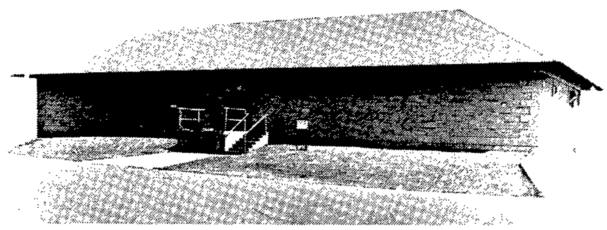
The real historic value of Watervliet Arsenal is its ability to convey the steady transition from early 19th century industrial techniques to up-to-the-minute manufacturing technologies. One or two buildings may not be historically significant in themselves but if they help show the development from one historical period to another they may be priceless.

The Arsenal tradition is one of preserving and making use of the past while blending it with the future. The original Big Gun Shop, Building 110 of the Arsenal, was built in 1889-1891, yet it stands only a few yards away from the new Building 35, one of the most modern industrial spaces to be found anywhere. And Building 110 continues to be a productive facility with changes in layout and equipment not affecting the historical value of the structure itself.

There are many architectural treasures. The original Powder Magazine with its four-foot-thick walls (to prevent accidental explosions from ripping through the walls and injuring workers in the days when powder was stored there) is now used as a laboratory. The present Officer's Club, a restaurant open to all employees, was built in 1840 as a laboratory. Quarter's No. 1, built in 1842, is still the residence of the commanding officer. The Iron Building, the only prefab cast iron warehouse building left in the United States, houses the Arsenal Museum and is a "must see" for students of architecture, history and civil engineering.

Even the massive Project REARM, the modernization program which aims at preparing the Arsenal for the 21st century, has been carried out without detriment to the historic value of Watervliet Arsenal.

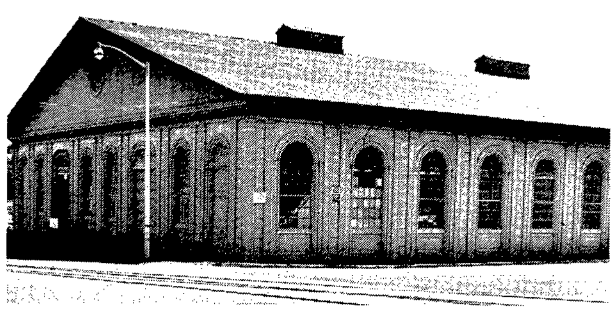
ORIGINAL POWDER MAGAZINE (1828)



OFFICER'S CLUB (1840) FIRST LABORATORY BUILDING

QUARTERS NO. 1 (1842) COMMANDER'S RESIDENCE

IRON BUILDING (1859) PREFAB CAST IRON WAREHOUSE



Brief Status Reports

Project 5068. New Anti-Corrosive Materials and Techniques (Phase III). Test vehicles have completed 20,000 miles of road tests without incident. A final report on this phase is being prepared. Procurement action was initiated for Phase III, long term marine environment exposure testing. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6038. High Deposition Welding. Flux core welding, H-plates welded. Submerged are welding parameters established. Narrow gap welding equipment being adjusted. Plasma M16 equipment being selected. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6054. Advanced Metrology Systems Integration. The state-of-the-art metrology system was completed. The needs analysis and SOA report are in process. Function models of current factory practice as revealed by industry surveys have been reviewed and approved. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6059-02. Self-Threading Fasteners. Program schedules completed. Areas of evaluation have been selected. Fasteners have been selected for testing and laboratory analysis. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6059-03. Adhesive Bonding. Program budgets and schedules completed. Production areas to be evaluated have been identified. Adhesives have been procured and laboratory testing has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6059-06. Laser Heat Treating. Fixtures and optical tools have been fabricated. Laser heat treating and metallurgical testing has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6059-08. Production Methods for Composite Turret Basket. Prototype fabrication was initiated. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6059-20. CARC Application Processing Technique. Paint test plan has been completed and approved. Robotic painting equipment has been procured, installed and debugged. Paint testing is continuing. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6067. Frame Welding Fixtures. Procurement package prepared for contractor effort. Contract has been awarded for the system design. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6076. Automated Depot Inspection of Roadwheels. The system was delivered to RRAD for acceptance testing. All road wheels scheduled for destructive testing thru May '83 will first be ultrasonically tested. The NDT data is being compared to establish the correlation factors. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6079-01. Monocrystal Alloy for High Pressure Turbine Blades. Tooling for first stage turbine blades shipped to TRW. Casting process definition has been completed. Solid blades are currently being evaluated by Avco Lycoming. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6079-02. Rapidly Solidified Technology -RST- Nickel-Base Superalloy. CAP process definition and CAP variability study have been completed. Different reductions in cross-rolling and heat treatment processes have been evaluated to establish the best combination of mechanical properties and microstructures. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6079-03. Bi-Cast High Pressure Turbine Nozzle. CAP process definition and CAP variability completed. Reductions in cross-rolling and heat treat have been evaluated to establish the best combination of mechanical properties and microstructures. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 6090. Tooele Army Depot Productivity Improvement Program. The majority of the preparatory work for the IPI program has been completed. The project is now awaiting further

funding enabling Phase I to begin. For more information, contact Don Cargo, TACOM, (313) 574-6065, 6378.

Project 5109. Precision Low-Cost Saw Delay Lines for UHF Applications. Phase II follow-on. TRW is establishing a pilot line to verify production techniques for saw devices. New go no/go routines point out deficiencies during and at end of fabrication process. Per unit cost will be reduced by a factor of ten. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5151. Liquid Phase Epitaxy of HGCDTE For Common Module Detector Arrays. Contractor will adapt liquid phase epitaxy (LPE) process for growing mercury-cadmium-telluride films on a production line for common module detector arrays. Will replace bulk-grone MCD arrays. For 60, 120 and 180 element arrays. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5174. CAM Sputtering Control for ZNO. A survey of manufacturers of computer controlled mass spectrometers was conducted. Procurement specifications were sent to industry. A search for a process that would benefit from CAM and would welcome our support has begun. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5180. MMT for Metal Dewar and Unbonded Leads. Honeywell and Santa Barbara Research Center will develop production processes for their respective metal dewar designs. These dewars replace the fragile glass design currently in use in the common module dewar. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5183. Production of Large Silicon for Laser Seekers. The westech zoner at Hughes produced two 3 inch diameter ingots. Resistivity test began at NBS. There is a delay in fabrication of split coil. Hughes is currently selling 1 inch diameter detector grade silicon to T.I. and Texas Optical Corp. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5193. Process Adjustments for Environmental Stress on Electronic Circuit Metals. Contractor is analyzing surface kinetics of electronic materials as they age. The firm is obtaining field data and defining chemical reactions, corrosion products, and film chemistry. An aging test is sought and will be validated. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 5196. Industrial Productivity Improvement—Electronics. Harris Corp. is analyzing their government information systems division for areas of improvement in both manufacturing and business systems. Will specify an approach for an efficient manufacturing capability. For more information, contact Joseph Key, ERADCOM, (201) 544-4258.

Project 7807. Programmed Optical Surfacing Equipment and Methodology (CAM). Polishing time reduced from 15 to 2 min. Breadboarding of process control interferometer and assembly/testing of auto lens blocking device in progress. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7916. Application of Low Cost Mandrel Materials. The sub-sized marage 350 mandrels coated with titanium oxide exhibited excellent adherence and hardness. A 105 mm mandrel is being detonation spray coated with tungsten carbide for forging trials. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7926. Hot Isostatic Pressing (HIP) of Large Ordnance Components. Two hipped low alloy steel billets received. Material currently being analyzed for chemical, metallurgical and mechanical properties. One preform finished machined into 8 inch M201 breech block. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7927. Generation of Base Machining Surfaces. The contractor, Computer Technology Corp., is currently involved in final assembly and testing of the equipment. The mechanical systems are 90 percent complete with four of the six axes functioning. The computer console and software are complete. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7928. Robotized Benching Operations (CAM). Work is progressing in development of robot programming language with completion in site. Also the data for the data base for the 8 in breeching coordinates is also nearing completion. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7940. Synergistic Platings With Infused Lubricants. Assembly of the facility for plating electrodeposited nickel phosphorus alloy was completed. The composition and operating condition of the developed bath has been identified. LFW-1 wear test specimens were coated for comparison to electroless nickel. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7949. Application of Group Technology to RIA Manufacturing (CAM). Part families for machined parts have been identified. Three of the part families are currently being analyzed. It appears the results of this program will be integrated into process planning functions. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7963. Group Technology for Fire Control Parts and Assemblies. GT scheduling program conversion is complete. The program is now available in fortran. A copy of the ICAM-GTSS software was requested. This software will be integrated with the present system. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7985. Small Arms Weapons New Process Production Technology. Physical work on ultrasonically assisted ejector drilling completed. Testing for ultrasonic gun drilling has begun. Testing related to single point chamber contouring has been inconclusive due to tooling problems. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 7985. Small Arms Weapons New Process Production Technology. An updated quote from GFM of America is being obtained and a supply of H-11 material with a homogeneous carbide distribution is on order for the cold forging of chambers task. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 8017. Pollution Abatement Program. The batch type recycling system for cutting fluids has been in full operation. About 120 machines have been cleaned up and placed in the progrram for periodic pump out and recycle. These machines have all used one particular fluid. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 5071-78. Automation of Analyis of EMI Data. The format for inputting EMI data to the data base has been established. Time to cost estimate for adding frequent allocation to equipment file (FABF) data to the computer data base was determined. For further details refer to final report. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-101. General Purpose Transportability Test Area. The MTD divisions most involved in transportability testing were identified. The requirement statement was prepared. Procedures were developed for obtaining assistance from MTMCTEA relative to testing of items for transportability. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-59. Solar Powered Instrumentation Van. The 3KW, 30KW hour solar cell power system has been delivered to WSMR from DOE for use with instrumentation van. The SCPS and instrumentation van are undergoing evaluation. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-76. Gamma Dosimetry Improvement and Modernization Program. A major portion of the gamma dosimetry processed during FY82 was in production support of the M1 abrams and BFU system. A major portion of work will be devoted to placing in routine operation microdosimetry for linac testing. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-90. Toxic Gas Analysis by Gas Chromatography. The prototype heating flushing system was modified. The im-

proved system will eliminate small leaks which occur when prototype is under high vacuum. An analyzer, based on an available laboratory infrared spectrophotometer was built. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-96. Calibration Procedures for TV Tracking System. Field data was acquired and statistically evaluated. Modified calibration techniques have been proposed including instrumentation procedures and data reduction techniques. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-97. Improved Methods for Performance Testing Mortars at Extreme Temperatures. As a result of meetings with artillery weapons specialists, preliminary chamber design has been developed. Pending further funds, the chamber will be fabricated from wood to verify the dimensions and interior clearances required for gun crew personnel. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-01. Acceptance Test Procedures. The central library for the total ATP program was maintained. The master ATP index and the ATP index supplements were published and distributed. For more information, contact John Gehrig, TECOM (301) 278-2375.

Project 5071-37. Roll-Over Tests of Military Vehicles. The first phase of this investigation was completed by Varigas Research, Inc. The report revealed 5 types of army vehicles were identified as having a high turn over history when involved in emergency maneuvers. The second phase is on-going. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-43. Test Automation. Several projects within this subtask have been completed. Some of the subtasks are avionics test, antenna pattern, and digital communication. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-60. Receiver Operating Characteristics Measurements. The first phase of the ROC methodology investigation has been completed. The investigation is in suspension until equipment is purchased through the instrumentation acquisition program in FY84. For more information, contact John Gehrig. TECOM, (301) 278-2375.

Project 5071-67. Interoperability Test Methodology. Testing has been completed and the final report has been submitted. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-71. Improved Copper Crusher Pressure Gages. The internal ballistics division., BRL, has completed its analysis of the gage parameters using finite elements as its means of analysis and an initial design has been completed. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-77. Electromagnetic Radiation Effects and Susceptibility of Army Materials. Several methods have been investigated for using the EMRE fac. Fiber optics data links for OPSEC communication and automated control of test item function was done. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 5071-95. Rapid Determination of Environmental Hazards. Work continued on the preparation of a comprehensive report dealing with rate and persistance of GB and VX in soil, water and vegetation. The first draft is complete. Work is continuing on the task. For more information, contact John Gehrig, TECOM, (301) 278-2375.

Project 6350-1802. M732 Field Artillery Fuze/S&A Transportation Vibration Test. The 18K shortfall to complete the project was obtained from AMMRC. Testing is continuing on four new groups of S&A devices. The measurements and data analysis are completed for the report written. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2224. Automated Antenna Pattern Measurement. The fabrication and testing of computer interfaces and their integration into the measurement system is completed. All major components of this system have been received and meet system requirements. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

be recorded. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2944. Protective Mask Canister Electromagnetic Inspection Procedures. The tester has been assembled and tested at the contractors facility. It performed in an acceptable manner in detecting fissuring and wall thinning type defects. Final debugging and reproducibility runs is finished. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2802. Pyrotechnic Ingredient Acceptance Test. Investigated means of determining the reactivities of metals by thermal analysis. Found that proposed test was not reproducible due to inability to obtain uniform oxidation of metals in thermobalance crucible. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2820. Integrated Focal Plane Module Test Station. The DEWAR was received and checked for leaks, continuity and temperature control. The original controller was found to be faulty and replaced. Problems remain with cabling, the DEWAR configuration and the cold shield. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2826. Liquid Chromatographic Analysis—Nitrocellulose Base Propellants. The progress of this project was presented to the JANNAF propellant characterization subcommittee in April. The work was well received and over 15 requests for reprints of the paper and previous reports were received. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 0904. Chemical Remote Sensing Systems. The interferometer design has been completed. Initial development testing indicated that the instrument was compatible with the XM21 military requirement. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 0905. Manufacture of Impregnated Charcoal-Whetlerite. Contract was awarded to Westvaco Corp. for design of pilot plant. Contractor completed review of government data and has begun set up of equipment to prepare samples. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 0909. Automated Agent Permeation Tester. Prototype has been assembled and component debugging is being conducted. Safety assessment and operating instructions are being reviewed. Preliminary demonstration was conducted. For more information, contact Richard Koppenaal, MPBMA, (201) 734-3551.

Project 0913. Spin Coating of Decon Agent Containers. Materials which were compatible with D52 were evaluated. For more information, contact Richard Koppenaal, MPBMA, (201) 734-3551.

Project 1001. Pilot Line for Fuze Fluidic Power Supplies. The test equipment designed and constructed under Phase II was completed. Fluidic generator performance changes dictated hardware changes in the machine. After completion of engineering changes the program was documented and finalized. For more information, contact Richard Koppenaal, MPBMA, (201) 734-3551.

Project 1318. Production, Fill, Close and Lap 8 in XM736 and BLU 80 Bomb. The Toledo weight system was installed at the pilot plant and the accuracy was evaluated. Two enclosures were fabricated to protect the QL from the effects of moisture during transfer and filling operations. Technical report is available. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 1348. Super Tropical Bleach. Work was completed on pre-pilot evaluations and optimization of the liquid reactor double salt process. Engineering design for the process has been completed. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 1353. Smoke Mix Process (Glatt). Prepared engineering change proposal and draft notice of revision for configuration control board. Prepared final technical report with incorporation of TECOM test results. For more information, contact Richard Koppenaal, MPBMA, (201) 724-3551.

Project 6350-2401. Cannon Tube Automatic Magnetic Borescope Inspection. The redesign of the scanning probe has been sent to the contractor for fabrication. Also, a number of system electrical problems were diagnosed and repaired. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2418. Half Life of Tritium Lamps. The technical work has been completed. The technical report is available. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2420. Optical and Dig Standards and Measuring System. The scratch scattering phenomenon study has been completed. The study recommended a scratch profile for the standards. The scratch standards were manufactured in accordance with MBS proposed scratch profile. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2603. Provide Auto Sphericity Interferometer for Test Lens Surfaces. The technical work has been completed. The final report is available. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2631. Critical Electromagnetic Inspection Problems Within the Army. The evaluation of the eddy current instrumentation was started. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2803. Automatic Measurement of Strength and Oxide Limiting Flaws in Ceramic Turbines. The objective of this effort was to develop the capability to correlate pore structure to strength limiting flaws. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2804. Binary Munitions Mechanical Rupture Properties Test. Prototype apparatus has been completed. The shuttle valve spool has been redesigned providing superior force balancing characteristics and easing manufacturing. Final drawings and instrumentation manual are in process. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2811. M42/M46 Magnetic Flux Leakage Inspection. The MFL inspection system design and standards have been reviewed. The fabrication of system is in process. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2815. Cannon Tube Automated Chrome Plate Thickness Measurement. The specification for the development and fabrication of the custom interface had been prepared and sent to procurement for review. Changes were proposed and the specification was revised. It is ready for solicitation. The fixture design is complete. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2817. Fiber Optic Cable Assemblies Test Criteria Development. After evaluating the proposal, it was concluded that the funds that were available were insufficient. AMMRC was advised of this situation. Additional funds were made available. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2828. Composite Motor Cases Acoustic Emission Proof Test Damage Evaluated. This project has been completed. The technical report has been submitted. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2829. Detector Dewar Microphics Production Test Set and Procedures. The final design of this test station is complete. Orders have been placed for much of the hardware (vibrational and electronics) under the IPE expansion contract. Test fixture design is still in progress. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2858. Stress Reading Transducer for Large Composite Components. The test fixture has been completed. A luna-pro photometer has been acquired. For more information, contact Paul Rolston, AMMRC, (617) 923-5466.

Project 6350-2943. Depleted Uranium KE Penetrators Ultrasonic Inspection Procedures. The sonic unit and the M774 S/N 735 heat treated standards were returned to Battelle Pacific Northwest Laboratories. In review the progress of the project, it was determined that the measurement of offset transducer distance need

New Approach to High Reliability

Leadless Components for Printed Wiring Boards

PAUL WANKO is a Project Manager in the Manufacturing Technology Division, System Engineering Directorate of the Army Missile Laboratory, U.S. Army Missile Command. After graduation from Pennsylvania State University with an Associate degree in Engineering, he came to Redstone Arsenal while working for the Navigation Division of the Bendix Corporation as a field representative on the PERSHING Missile System. He began working for the Guidance and Control Directorate of the Army Missile Command in 1965 as a packaging designer and since has contributed to the designs of many Army missiles and launches. In 1970 he headed up the Hybrid Microelectronics Design Group in support of the new Hybrid Laboratory at the Missile Command. A few of his hybrid microelectronic designs are Range Safety devices, Detector Preamplifiers and Missile Auto Pilot. He is currently managing several MM&T projects and is responsible for the progress and reporting of these projects. He is a member of International Society for Microelectronics, Huntsville, AL chapter.

Higher reliability of printed wiring boards was achieved by the U.S. Army Missile Command when the printed wiring board was fabricated from a laminate whose coefficient of expansion approximates that of a leadless chip carrier and which then was bonded to a thermal mounting plate which constrains thermal expansion. This stabilized system reduced the number of fractures of the solder joints from fatigue when the board was thermally cycled.

Under direction of the System Engineering and Production Directorate, the ground systems group of Hughes Aircraft Company conducted a program which was directed toward the establishment of low cost/reliable manufacturing technology for the direct attachment of leadless hermetic chip carrier packages to printed wiring boards.

Leadless components are presently being used in the electronics industry to increase component density, improve electrical performance, and reduce assembly costs. When the leadless chip carrier is directly attached to the printed wiring board solder acts as both the electrical and mechanical connection. Since leadless chip carriers are devoid of leads, any mismatch of coefficients of thermal expansions between the printed wiring board and leadless chip carrier will result in stress on the solder joints during thermal cycling and subsequent failure of the solder joint from fatigue after a certain number of cycles.

Existing co-fired ceramic multilayer technology circumvents the above problem by utilizing an alumina substrate whose coefficient of thermal expansion matches that of the chip carrier. While the use of the ceramic substrate offers reliable surface mounting of leadless chip carriers, the

NOTE: This manufacturing technology project that was conducted by Hughes Aircraft Company was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The MICOM Point of Contact for more information is Mr. Paul Wanko, (205) 876-7079.

disadvantages are high cost, size restriction, weight, high dielectric constant, and availability of suppliers.

Present-day printed wiring board materials of either epoxy/glass or polyimide/glass are not thermally compatible with leadless chip carriers. Differences between their coefficients of thermal expansion and the leadless chip carrier cause stresses in the solder joints when subjected to thermal cycling over larger temperature extremes. Proposed methods for reducing the coefficient of thermal expansion mismatch are leaded carriers, socketing of leadless chip carriers, thick leadless chip carrier/printed wiring board solder joints, which significantly reduce the level of stresses in the joint, require additional operations while creating processing problems. The use of a low-expansion organic material, such as a polyimide/Kevlar, solves the coefficient of thermal expansion mismatch and greatly reduces or eliminates solder joint cracking.

Primary and Secondary Criteria Established

The primary objective of this program was to develop the manufacturing techniques/processes for production of printed wiring boards utilizing leadless components. The following requirements were established to meet this objective:

Primary Criteria

- Material Properties—Materials must have properties conductive to existing PWB technology and capable where necessary of surviving the various processing environments

- Fatigue Life of Solder Joints—The selected materials and processes must reduce the stress level on the solder joint thereby enhancing its fatigue life in thermal cycling..

- Cost—The system cost must be equal to or less than that for printed wiring boards utilizing through hole mounted components.

- Reliability—Printed wiring assemblies populated with leadless components must be capable of maintaining electrical and mechanical connections under the required environmental conditions.

Secondary Criteria

- Fabrication—Printed wiring boards must be capable of being fabricated by processes considered standard in the printed wiring board industry.

- Assembly—Assembly of leadless components must be adaptable to automated high volume production methods.

- Repairability—Removal and replacement of leadless components must be readily accomplished without degrading the printed wiring board and electrical performance of the component.

Material Evaluation and Selection

Material evaluation and selection (Phase I) commenced with a cursory industry/literature search with a list of the possible materials for the packaging/interconnection substrate materials and their assembly. The survey comprised a review of the literature in the field of leadless chip carrier technology with specific emphasis on the matching of the thermal coefficients of expansion of the chip carrier and the printed wiring board. The principal data sources for bibliographic material are listed in Table 1.

- Defense Document Center
- Engineering Index
- Institute of Printed Circuits
- National Technical Information Service
- Electronics Industry Association
- California Circuits Association

Table 1

The information gathered during this task included sources of laminates, solder pastes, thermal conductive compounds, chip carriers, adhesives, and thermal mounting plate materials. This information was used to establish a screening program for the materials for evaluation in Phase I.

Also, principal manufacturers of military and industrial electronic assemblies were surveyed at the beginning of this program to identify those firms utilizing printed wiring boards with directly attached leadless chip carriers.

All materials were reviewed from the standpoint of manufacturing, processing, and commercial availability. The preliminary review focused on modified polyimide/Kevlar as the substrate material. Solder pastes were characterized for their alloy content and ability to produce a dense, concise repeatable solder print. Thermal mounting plate adhesives were evaluated for their ease of processing and ability to withstand adverse environments. Thermal

undercoats were screened primarily for ease of application and removal and thermal conductivity. The thermal management addressed the efficiency of various conduction modes in dissipating heat from the chip carrier.

Evaluation and Selection of Printed Wiring Board Materials

Increasing demands for very high-speed information processing and large-scale integration require an increase in package density conducive to the use of leadless chip carriers on printed wiring boards. Since the leadless chip carrier is directly attached to the printed wiring board by soldering and there is an absence of leads on the package, the thermal mismatch between them incudes a high stress level in the solder joint, thereby resulting in a reduced fatigue life during thermal cycling. An increase in the number of cycles to failure is directly related to

(1) A decrease in the difference in coefficients of thermal expansion between the printed wiring board and leadless chip carrier
(2) An increase in the thickness of the solder layer
(3) A decrease in the range of thermal cycling
(4) A decrease in chip size.

The selection of a compatible interconnection system ultimately is related to a reduction in the total change of strain induced in the solder joint by thermal cycling. Figure 1 shows a simplified dimensional analysis of the effect of temperature on the solder joint.

Basic Approaches Proposed by Industry

Primary emphasis on industry has been placed on extending fatigue life by minimizing the thermal coefficient of expansion difference between leadless chip carrier and printed wiring board. The basic approaches used to improve the reliability of the solder joints include the constrained expansion method, controlled method, and complicant method.

- **Constrained Expansion Method**

The constrained thermal mounting plate approach is a method inclusive of a low-expansion substrate design either as a bond material for the substrate frame (Figure 2) or as a composite to reduce substrate expansion (Figure 3). In the plan view of of Figure 2, conventional printed wiring boards fabricated and bonded with a rigid adhesive to a low coefficient of thermal expansion metal core as copper clad Invar or copper clad molybdenum will be controlled by the metal core in the X and Y axes. However, there are several design considerations for this type of construction that must be followed. If not, the effectiveness of the constraint would be greatly reduced. These considerations are:

(1) The thickness ratio of the low expansion metal to the PWB and
(2) The thickness of the bond line. The thickness ratio between the metal and printed wiring board is derived from the thermal coefficient of expansions and the elastic modulus of the materials. The thickness of the bond line should be kept to a minimum for a maximum restraining effect.

In Figure 3 the thermal coefficient of expansion of the composite can be controlled through the use of a low expansion metal layer such as copper clad Invar or graphite laminated between the high-expansion substrate printed wiring board material. In such composites, the overall thermal coefficient of expansion can be controlled to the

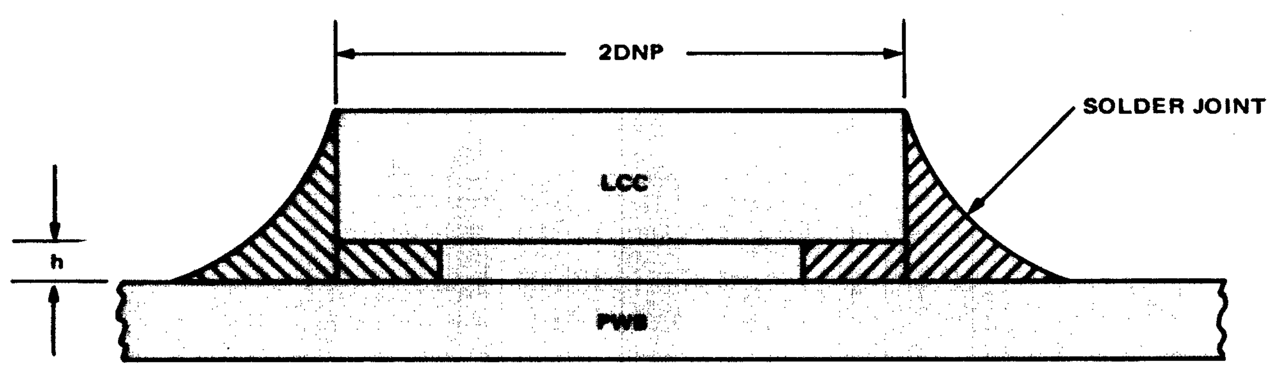


Figure 1

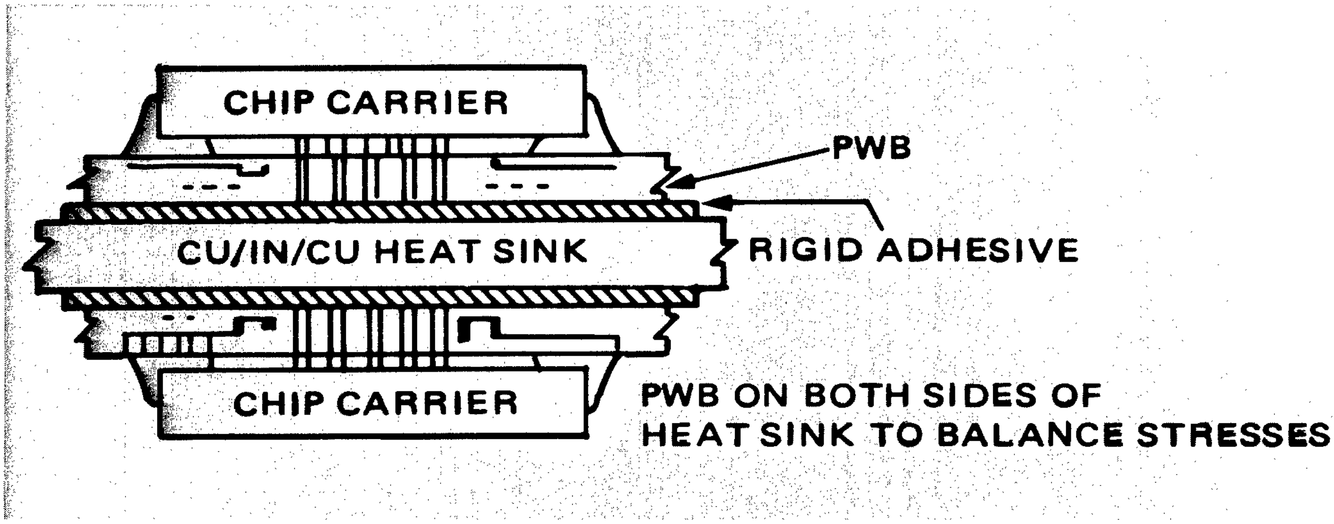


Figure 2. Constrained Expansion Design Utilizing Low Expansion Materials as Substrate Frame Bonds

level of that of the leadless chip carrier. Other derived benefits of the composite substrate are:

(1) The metal foils can serve as power and ground planes in the circuitry and

(2) The thermal properties of the composite substrate can be improved because of the presence of the metal or graphite layers. The graphite is advantageous as a low weight/high thermal conductivity internal layer of the printed wiring board. However potential problems arise from its inherent high electrical conductivity and the possibility of misregistration in fabrication of large sizes.

- **Controlled Method**

The simplest physical approach is a design wherein a low expansion organic or inorganic system (as shown in Figures 4 and 5) with an inherent closer matching thermal coefficient of expansion is used as the substrate for the leadless chip carrier. This material system would directly extend the fatigue life of the solder joints during thermal cycling. Candidate materials for the organic system are Kevlar epoxy or Kevlar polyimide, polyimide-glass, and polyimide-quartz. Co-fired ceramic, ceramic thick film, and porcelainized ceramic represent he inorganic systems.

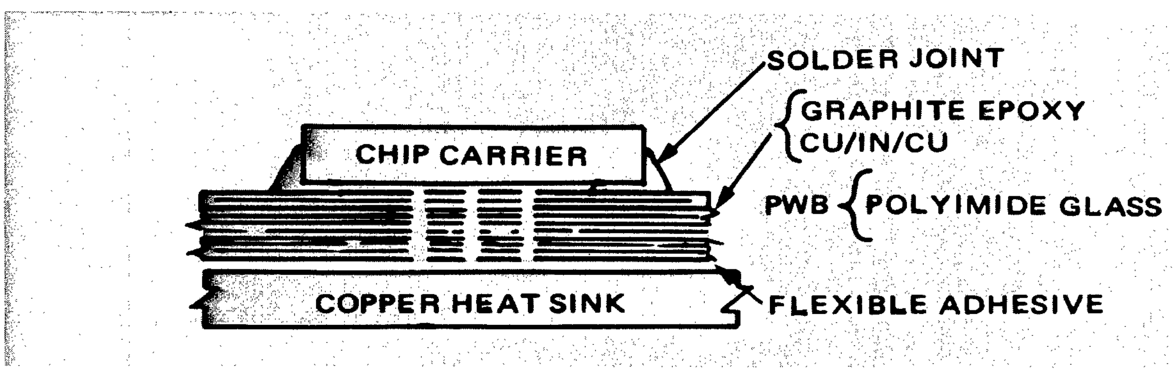


Figure 3. Constrained Expansion Design With Low Expansion Materials in the PWB

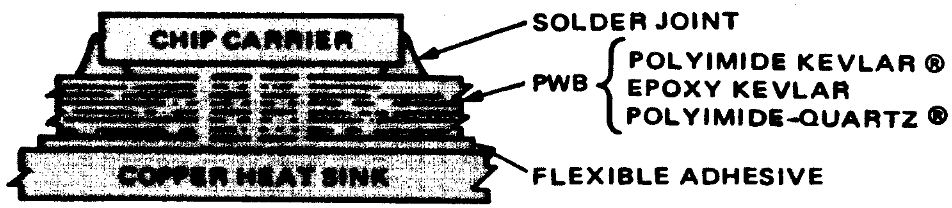


Figure 4. Organic Controlled Expansion

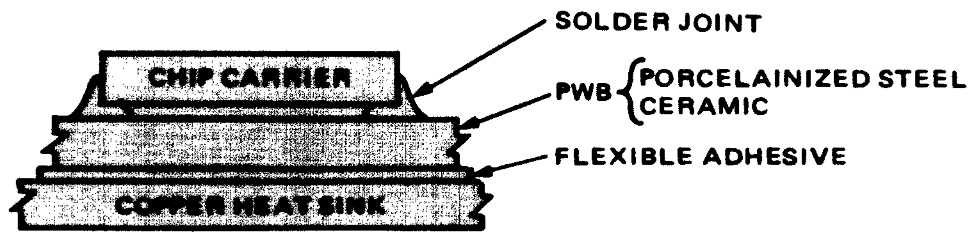


Figure 5. Ceramic or Porcelainized Steel
(Controlled Expansion)

- **Compliant Method**

This design compensates for differences in thermal coefficient of expansion between the printed wiring boards and leadless chip carrier by:

(1) Distributing the net strain and strain energy over a larger area through flexibility in the solder joint (Figure 6)
(2) Reducing differences in applied solder strains through the placement of a compliant layer between the footprint of the solder joint and the printed wiring board (Figure 7) and
(3) Transmitting the strain of the thermal coefficient of expansion mismatch directly from the leadless chip carrier to the printed wiring board by placing a thermally conductive compound into the air gap beneath the leadless chip carrier (Figure 8).

Of these methods, those which appear most promising are the compliant layer substrates which utilize the principle of reducing the equivalent elastic strain by interfacing the component pads and conductor pattern and substrate with an elastomeric coating. Several patented systems utilizing this technique are now available on the market. Data on the reliability of this system is scarce, although it is known that the strain on the solder joints of the leadless chip carrier is considerably reduced by the compliant layer. A possible problem with plated through holes could arise from the high Z-axis expansion.

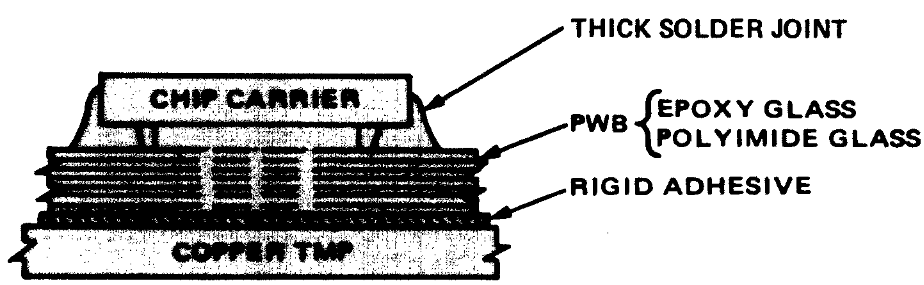


Figure 6. Unconstrained Joint Configuration

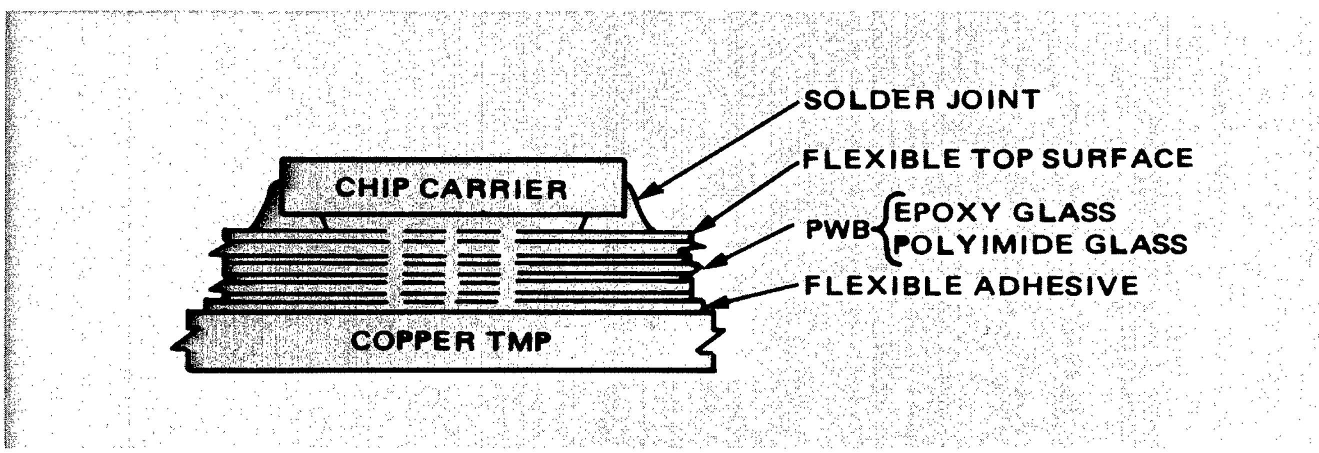


Figure 7. Flexible Surface Layers

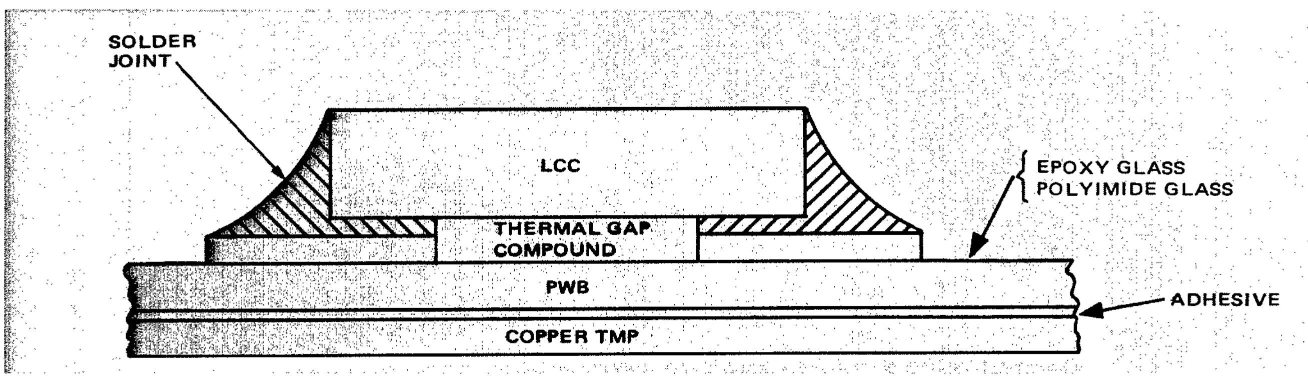


Figure 8. Thermal Compound Distributes Stress from TCE Mismatch

Preliminary Conclusions

After completion of this phase of the work, several conclusions were reached:

- Kevlar reinforced polyimide was selected for use as printed wiring board material because its thermal coefficient matches closely with that of the ceramic leadless chip carrier. The physical and electrical properties of the material have been investigated and were found to be acceptable for military application.

- Solder pastes from a number of manufacturers were evaluated in percent solid content, oxidation resistance, and screenability tests. Additionally, the particle shape and size, activity of the flux, and flux content of the pastes were evaluated. For consistency, one solder paste was used throughout the program.

- Adhesives for bonding printed wiring board to thermal mounting plate were selected and evaluated. Bonding printed wiring board to thermal mounting plate prior to soldering was found impractical because of the interference in injecting the thermal undercoat. The adhesive used was selected because of its low curing temperature, ease of application and removal of the thermal mounting plate from the printed wiring board, high thermal conductivity, and the ability of reducing warpage in the bonded

- An alumina filled epoxy, was selected for the thermal undercoat because of its low viscosity and high thermal conductivity. Low viscosity was necessary for injecting the thermal undercoat into the gap between the leadless chip carrier and the printed wiring board.

Thermal analysis was performed for the printed wiring board/thermal mounting plate assembly using computer modeling. A three dimensional resistive network model

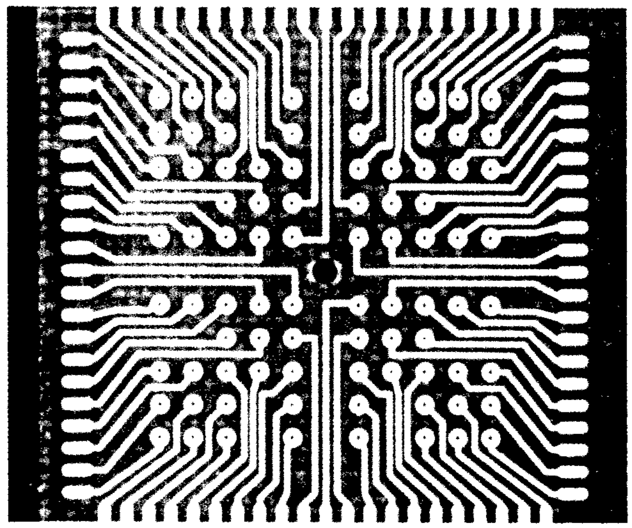
was developed to simulate the thermal characteristics and response of the circuit cards. In addition to the computerized thermal analysis, actual thermal measurements were made on the circuit cards to provide empirical data for checking the computer results. The results of the theoretically and empirically obtained data correlated in most cases. The results showed that the alumina-filled epoxy reduces the thermal resistance between the leadless chip carrier and the printed wiring board in most cases. The effect of filling the vias with solder was the greates for the small leadless chip carriers. For the large leadless chip carriers, the improvement was very small over the non-filled vias.

Process Development

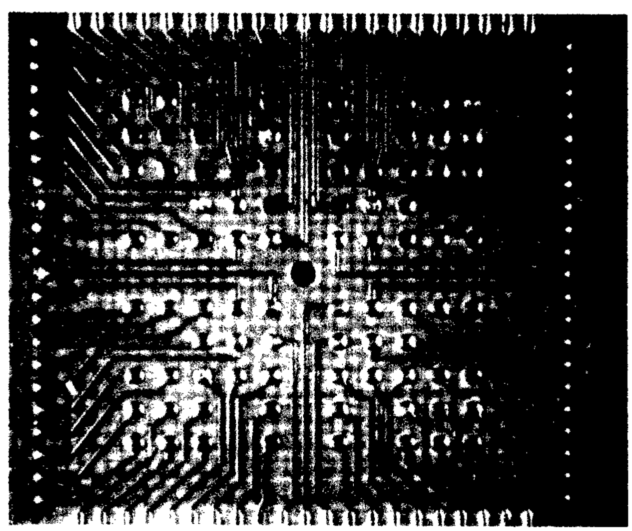
Process development (Phase II) concentrated on determining the optimum methods for attaching leadless components to rigid and rigid-flex fine line circuits utilizing the materials selected in Phase I. Test boards were fabricated from both polyimide/glass and modified polyimide/Kevlar with high density circuit designs. Printing parameters for solder pastes from Phase I were optimized with both manual and automated screen printers. Procedures for (1) semi-automatic tinning, (2) removal and replacement of leadless components, and (3) application of the thermal undercoat were developed. Attachment of the leadless components to the printed wiring board by conveyorized belt furnace reflow and vapor phase condensation soldering was evaluated. Cleaning of the soldered printed wiring assemblies (printed wiring assemblies) by standard operation and with common industry solvents was examined. Procedures for bonding the printed wiring assemblies to thermal mounting plates were established using materials selected in Phase I.

Methods of filling the vias as wave soldering or plating and fusing were examined as their repeatability and process feasibility. It was found that extremely rigid control of wave soldering parameters was necessary to ensure completely filled vias. Tinning of leadless chip carriers with solder by static and wave soldering methods was evaluated by visual inspection for uniform coverage of castellations of the leadless chip carrier and by scanning electron microscope for gold contamination of the solder. Solder prints were deposited on the footprints of the printed wiring board with a manual screen printer and inspected for pattern definition (Figure 9). Both vapor phase condensation and conveyorized belt furnace soldering were assessed as to their effect on substrate materials and the ability to yield solder joints (Figures 10 and 11).

Manual placement of leadless chip carriers on substrates was found to be labor intensive and fatiguing to personnel. Automatic pick and place equipment was assessed as to their rate of placement, cost, and maintenance (Figure 12). Adhesives for bonding the printed



Prior to Fusing (3X)



After Fusing (3X)

Figure 9.

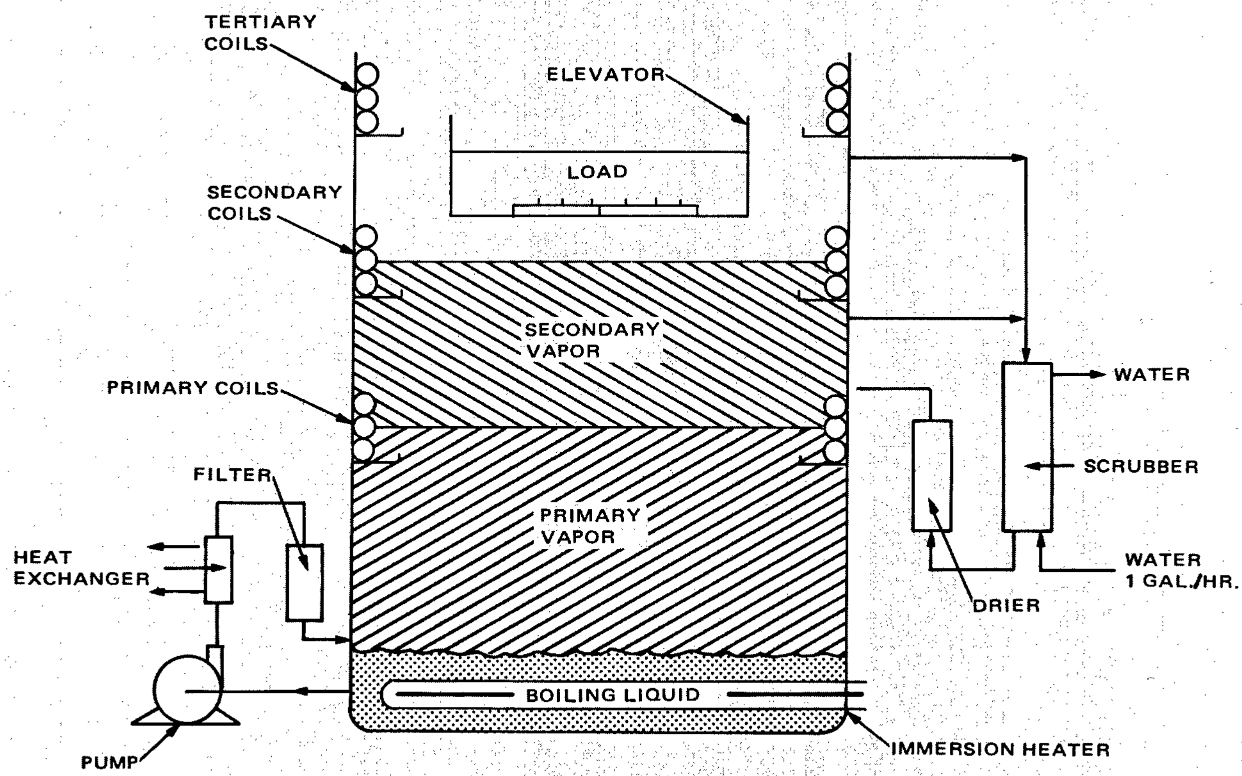


Figure 10

wiring board to the thermal mounting plate were evaluated for their resistance to adverse environments and ease of application and removal from the thermal mounting plate. A method of applying the thermal undercoat was developed which includes the use of a specific injection hole size and semiautomatic equipment. Additionally, a procedure for removal and replacement of chip carriers and the undercoat was developed. Cleaning solvents wee utilized which would solvate the residual flux thereby yielding an assembly conforming to the cleanliness requirements of MIL-P-28809. Board cleanliness was determined prior to and after attachment of the leadless chip carriers by employing an Omega Meter. Conformal coatings meeting the requirements of MIL-I-46058 were assessed as to their environmental resistance and ease of application and rework.

Environmental Testing

Environmental tests were conducted on a significant number of printed wiring boards assembled with leadless chip carriers. Tests were performed for two conditioins—i.e., with and without a thermal undercoat. Humidity, vibration, and thermal cycling tests were conducted in accordance with MIL-STD-202E, whereas acceleration and mechanical shock testing conformed to MIL-STD-883, Condition E. The test levels in each test were selected to provide a damage potential well above that resulting from a typical qualification test. Verification of the ability of the assemblies to meet the test requirements was effected by visual and microscopic examination of the printed wiring boards after each increment of environmental test. Damage made to component packages was noted and identified. Since the initial packages tested for mechanical shock failed, the severity level was reduced until package survival was obtained on consecutive test specimens.

Visual inspections were performed with a light microscope to magnify the leadless chip carrier, solder joints, and other areas of the assemblies. These inspections were performed on each leadless chip carrier and each joint during each inspection period.

This study included five different sizes of leadless chip carriers chosen to provide a representative spectrum of those commonly available, as shown in Figure 13.

Four different printed wiring board patterns were used

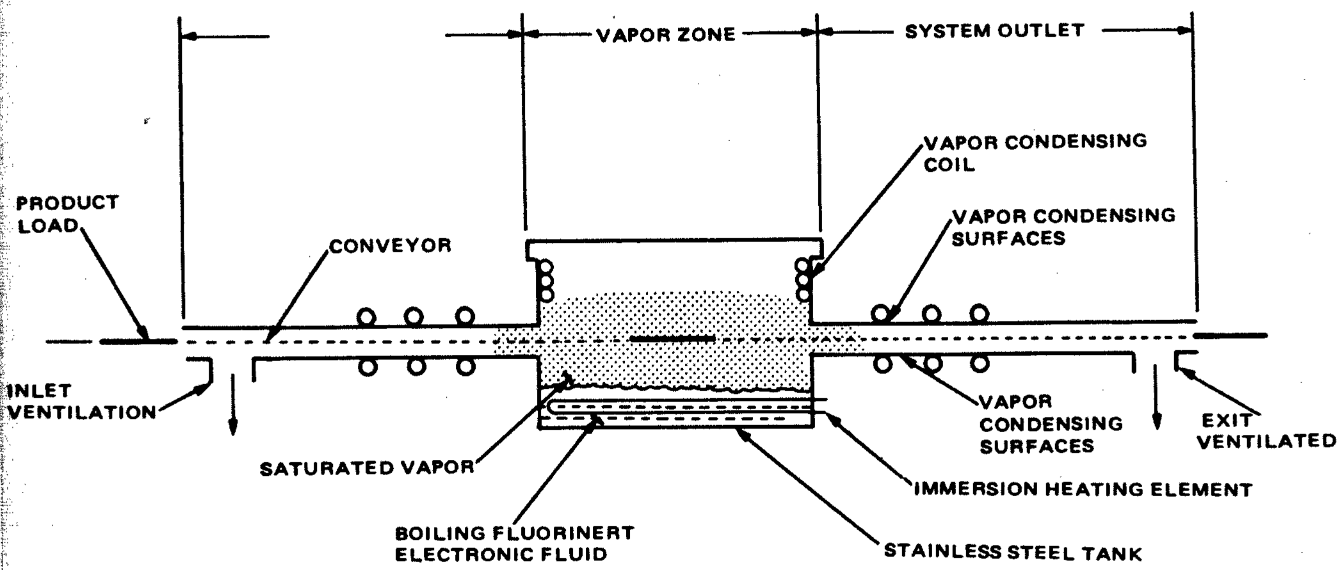


Figure 11

for the test assemblies. Previous investigations at Hughes established the pad sizes, thermal via dimensions, and other details as significant design considerations for the manufacture of reliable leadless chip carrier assemblies. Only processes developed for large-scale manufacturing were used to fabricate these assemblies.

These assemblies were typical of those suggested for military hardware. Close packing of leadless chip carriers allowed a maximum usage of materials and space and provided a worst case condition for these environmental tests because of the greater difficulty of conformal coating assemblies prior to humidity testing, greater rigidity of the printed wiring assembly during thermal cycling, and greater mass of the printed wiring assembly, which causes greater deflection during vibration.

The samples prepared for shock and acceleration testing differed only slightly from those prepared for the thermal cycling, vibration, and humidity testing. The available shock and acceleration test equipment limited the size of these test samples. Therefore, leadless chip carriers were assembled onto printed wiring boards identical to those used for thermal cycling, vibration, and humidity testing. Subsequently, sections were cut from these assemblies for shock or acceleration testing.

All printed wiring assemblies, prepared according to those processes identified in Phase II, were tested on both modified polyimide/Kevlar printed wiring boards and polyimide/glass printed wiring boards mounted on standard 0.050-inch-thick copper. The Kevlar printed wiring board material matches the coefficient of thermal expansion of the leadless chip carrier, the polyimide/glass material was used as the control.

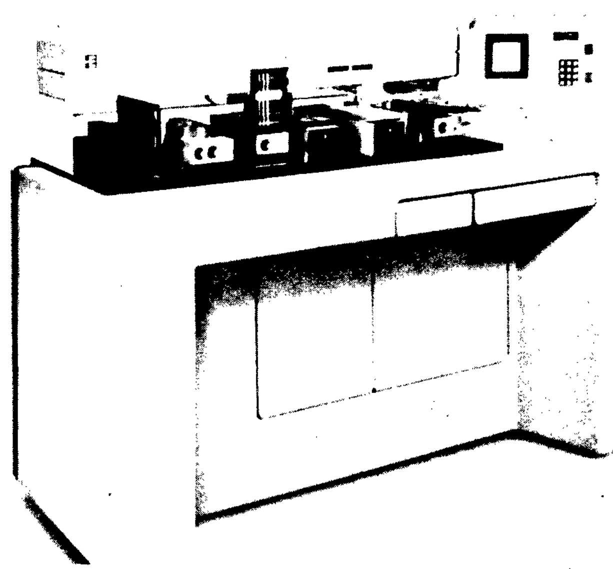


Figure 12

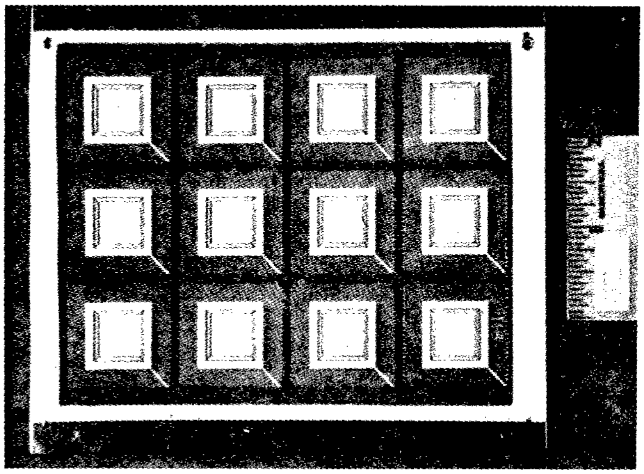


Figure 13

All five sizes of leadless chip carriers, undercoated and mounted on both modified polyimide/Kevlar printed wiring boards and polyimide/glass printed wiring boards bonded to copper thermal mounting plates, were tested in humidity, vibration, shock, acceleration, and thermal cycling. Thermal undercoat was injected beneath the leadless chip carrier to fill a circular radius tangent to the leadless chip carrier for heat dissipation.

In addition, several tests were performed to ascertain the effects of processing variables on package reliability. These leadless chip carriers were the most sensitive to environmental effects and therefore amplified the effects of material and process variations. These tests evaluated the effects of

(1) Reinforcing the joints with a rigid epoxy
(2) Eliminating the thermal undercoat and
(3) Using a copper-clad Invar thermal mounting plate on the survivability of leadless chip carriers attached to polyimide/glass printed wiring boards during thermal cycling. The leadless chip carriers without a thermal undercoat were also tested in vibration, shock, and acceleration for polyimide/glass printed wiring boards mounted on copper thermal mounting plates to determine whether the undercoat significantly enhanced package directly reliability. For the same reason, leadless chip carriers without the thermal undercoat and mounted on modified polyimide/Kevlar printed wiring boards bonded to copper thermal mounting plates were tested in acceleration.

Data from the environmental tests were analyzed to estimate the reliability of the mechanical and electrical interconnections under the specified environmental conditions. The data analysis presented the observed failure rate compared to the increments of damage potential for each environment.

Environmental Testing Conclusions

Printed wiring assemblies fabricated from the materials selected in Phase I and assembled in accordance with the assembly processes developed in Phase II of the program were tested in humidity, vibration, shock, acceleration, and thermal cycling. The results indicated that printed wiring assemblies subjected to humidity test showed no corrosion or any other form of degradation. Neither the printed wiring board, thermal mounting plate, adhesive, conformal coat, or coating was affected by the humidity testing. In vibration testing, all the printed wiring assemblies, with one exception, passed the severe vibration test requirements. The exception was found in the leadless chip carriers without the undercoat, wherein those showed a sign of solder joint cracking.

The results of shock testing indicated that the thermal undercoat apparently enhanced the survival level of the packages, as indicated by the test performed on the leadless chip carriers without an undercoat in the space between the printed wiring board and leadless chip carrier.

The leadless chip carriers mounted on polyimide/glass or modified polyimide/Kevlar printed wiring assemblies sustained no damage from an acceleration test. Greater G levels cracked leadless chip carriers in the same manner as mechanical shock, and failures occurred during acceleration perpendicular to the plane of the printed wiring boards. No other damage or degradation of the assemblies was detected after testing.

Modified polyimide/Kevlar printed wiring boards attached to copper clad Invar thermal mounting plates provided the greatest reliability for thermal cycling tests. Both undercoated and nonundercoated leadless chip carriers mounted on these assemblies survived over 400 thermal cycles without any solder joint cracking. The packages directly attached to modified polyimide/Kevlar printed wiring boards mounted on copper thermal mounting plates survived 600 cycles and 1000 cycles without solder joint cracking, respectively. It was believed that the life of the solder joints of these packages could be extended if the thermal mounting plate were copper clad Invar. Because packages fractured when mounted on the modified polyimide/Kevlar—copper thermal mounting plates assemblies in the first 20 cycles of testing, no additional tests were performed with these packages. Again,

it was believed that the life of the solder joints of these packages could be extended beyond the 400 cycles obtained for the larger packages if copper clad Invar thermal mounting plate were used.

Most of the leadless chip carriers of polyimide/glass printed wiring boards bonded on copper assemblies, experienced solder joint cracking in less than 100 thermal cycles and only one survived 200 cycles. Additional tests with leadless chip carriers using polyimide/glass printed wiring boards and techniques to extend solder joint life were found either unacceptable for manufacturing or ineffective.

Chip discrete components were subjected to thermal cycling. Barium titanate chip capacitors fractured in the ceramic body after testing. No physical or electrical damages were detected in the tantalum chip capacitors and chip resistors.

Modified polyimide/Kevlar exhibited early resin cracking in the thermal cycles. However, resin cracking did not lead to the degradation of the board. The use of Kevlar paper greatly reduced the amount of resin cracking in the laminate. The results for the paper reinforced material, however, are incomplete at this time.

Barrel cracking was evidenced in both the modified polyimide/Kevlar and polyimide/glass boards after the thermal cycling. However, in most cases, the cracks failed to traverse the plating in the plated through holes, which were more prone to barrel cracking for the Kevlar reinforced boards than the glass reinforced ones because of the slightly greater Z-axis expansion of the Kevlar.

Trade-Off Analysis Conducted

The trade-off analysis encompassed the trade-offs and changes involved in the utilization of leadless chip carriers and other leadless components on printed wiring boards. The objectives of the trade-off analysis were:

- Establish the criteria for achieving a highly reliable interconnection system for leadless chip carriers for use in diverse environments and military applications.
- Maximize the highly integrated circuit density inherently associated with printed wiring boards populated with leadless chip carriers.
- Minimize the impact of leadless chip carrier technology on design activities and manufacturing operations.

Specific areas addressed included:

- **Component Packaging**
  - Leadless vs Leaded Chip Carriers
  - Package Materials and Construction
  - Functional Density
  - Electrical Performance
  - Thermal Characteristics
  - Weight
  - Size
  - Cost
  - Repairability
  - Testability
  - Reliability
  - Standardization
  - Availability
- **Interconnection**
  - Package/System/Thermal Mounting Plate Concepts
  - package/Leadless Chip Carrier Interconnection Substrate Materials
  - Thermal Mounting Plates
  - Thermal Management
- **Manufacturing**
  - Assembly
    - Solder
    - Plating and Preparation of Printed Wiring Boards
    - Application of Solder Pastes
    - Component Placement
    - Soldering
    - Cleaning—Flux Removal
    - Application of Thermal Undercoat
    - Attachment Sequence for Leadless Chip Carriers
    - Conformal Coating
    - Removal and Replacement of Components
  - Inspection
    - Visual
  - Reliability of Leadless Chip Carrier Populated Assemblies

Costs play a big part in this analysis and deserve specific attention. Costs for assemblies populated with surface mounted leadless components depend on various factors. Generally cost reductions are realized through a reduction in the number of printed wiring board assemblies required. Individual assemblies will be more complex because of their higher density.

Prime candidates for leadless chip carriers usage are those assesmblies with high density and conventional components. Usually this type of assembly presents difficulties in manual operations because its complexity leads to human errors. Robotic placement of components is repeatable and prone to very few errors.

A fairly simple assembly requiring a few smaller packages will cost more in the conversion of through hole mounted components to leadless chip carriers. The volume also plays a significant role in the feasibility of the decision to change to leadless components. The prime overriding factor for deciding on converting double inline packages, e.g., to leadless chip carriers on an assembly is the certainty that the production cost for a leadless chip carrier will decrease in future years. As with most emerging technologies, the high cost of leadless chip carriers presently is a temporary condition. Price parity is expected to be attained in the near future.

Low density circuits with low labor are unlikely candidates for leadless chip carriers usage unless high reliability and smaller size are weighting factors wherein leadless chip carriers should be only used if a large production run dictates their use.

Economic considerations for the use of leadless components include the component availability and cost. Both considerations must be assembled into a cost factor related to the cost of inventory and lead time. In many instances, the initial cost of a component is minimal compared to the true "assembled" cost. Availability of components significantly adds to the cost of assemblies populated with leadless chip carriers. However, the availablity follows a diminishing cost curve because of the increase in availability of parts with time.

The future of direct attachment (surface mounting) of leadless chip carriers depends greatly on the high volume assembly equipment and machinery. Such equipment is sophisticated and expensive with manufacturers producing equipment with improved capabilities and of lower cost every year. The significant point for consideration is the production rate in units per hour since higher rates reduce the cost per part.

The breakeven point for the leadless chip carrier technology is quite evasive as is true for any new technology. Factors of labor content, size, density of circuits, reliability, environmental service, and volume of printed wiring assemblies should be included in the formula for evaluating the breakeven point. The components of the system for producing a leadless chip carrier populated assembly greatly affects the final cost because direct attachment of leadless chip carriers is a method dominating technology.

A substantial output of the leadless chip carrier technology to date is its potential for substantial reduction in cost because of the following:

- The intrinsic cost of the materials are less. Axial or radial lead passive components are more expensive because they use more material and require additional operations to attach the leads. Leadless carriers have one-fifth the material and require no glass to metal seals.

- High-speed microprocessor controlled pick-and-place equipment are used to attach the leadless chip carriers to boards. The cost of this equipment is a fraction of the dual-in-line insertion equipment. Because leadless chip carriers self align during the solder reflow operation, high-speed placement leadless chip carriers with reasonable accuracy is sufficient to meet manufacturing requirements.

- Because leadless chip carriers are very small, large quantities can be kept in various configurations as on tape, in cartridges, or in matrix holding fixtures. Automatic or semiautomatic high speed loading is possible. In many cases, the high-speed pick-and-place equipment can be designed to handle parts as received from the part manufacturer without any additional handling or component preparation thereby reducing costs.

Design Guide

As part of this work, Hughes also prepared a design guide. Specifically, this guide covers the factors to be considered when directly attaching leadless components to modified polyimide/Kevlar printed wiring boards. Included are the requirements for materials, processes, and assembly. The characteristics of the substrate together with thermal management, inspection, rework, testing, etc. are discussed.

As stated in the guide, the etched foil circuit is the most widely printed circuit for military applications. The etched circuit board consists of a precisely etched circuit pattern adhesively bonded to an insulating base of polyimide glass or modified polyimide/Kevlar and provides a means for the support and interconnection of components to be mounted on the board. The etched board is fabricated with printed wiring on one or both sides.

Multilayer boards used in designs requiring very high packaging density possess three or more layers of printed wiring. Connections between layers on etched boards are achieved by plated-through holes.

Process Demonstrated

The materials and processes from Phases I and II were implemented into a pilot line. The line was designed for a prototype production run of 10 boards of at least 7 x 7 inch multilayer boards to verify the manufacturing process.

Information on procedures commonly associated with the attachment of leadless chip carriers to printed wiring boards was provided by the pilot production run. Flatness of the printed wiring board laminate, screen printing of solder pastes, and vapor phase soldering parameters were confirmed. Practices such as storage conditions of solder pastes and shelf life of screened solder deposits were found to require strict adherence to established requirements.

The pilot production line produced 30 boards populated with leadless chip carriers for delivery to the Missile Command for demonstration and evaluation, of which 20 each were double sided printed wiring boards and 10 each were rigid-flex boards with circuitry on each side interconnected by a plated-through hole.

During this phase of work, a set of 104 slides depicting the procedures and processes on the pilot line and a 10-minute movie film were made and delivered to MICOM.

The pilot line was implemented at the beginning of Phase V. A flow chart of the operation is depicted in Figure 14. Figure 15 follows the flow of the tinned leadless components from incoming storage through the various processes to final inspection.

Multilayer boards and rigid-flex boards were fabricated in a production mode utilizing modified polyimide/Kevlar material in their designs, with a combination of leadless and discrete components on the same multilayer board and on rigid-flex assemblies.

The design for the boards was submitted to and approved by MICOM prior to their fabrication. Double-sided (20 each) and rigid-flex (10 each) assemblies were fabricated over a period of 8 weeks and populated with leadess components.

Principal Conclusions and Recommendations

- **Conclusions**—The principal conclusions reached in this program are summarized in Table 2. It was concluded that optimum fatigue life of thermally cycled solder joints results when leadless chip carriers are directly attached to a modified polyimide/Kevlar substrate mounted on a copper-clad Invar thermal mounting plate. The matching coefficients of expansion of the leadless chip carrier,

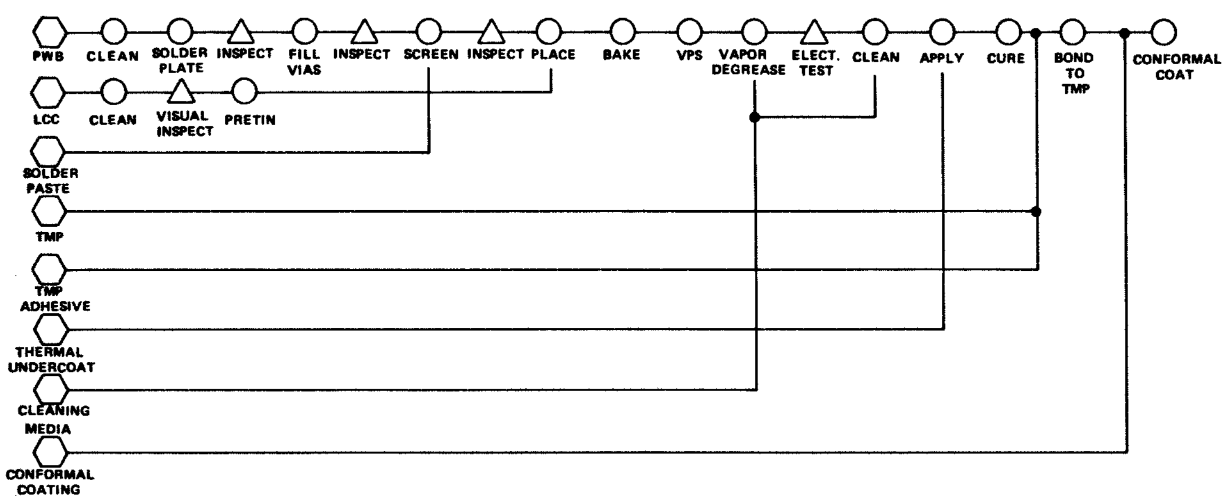


Figure 14

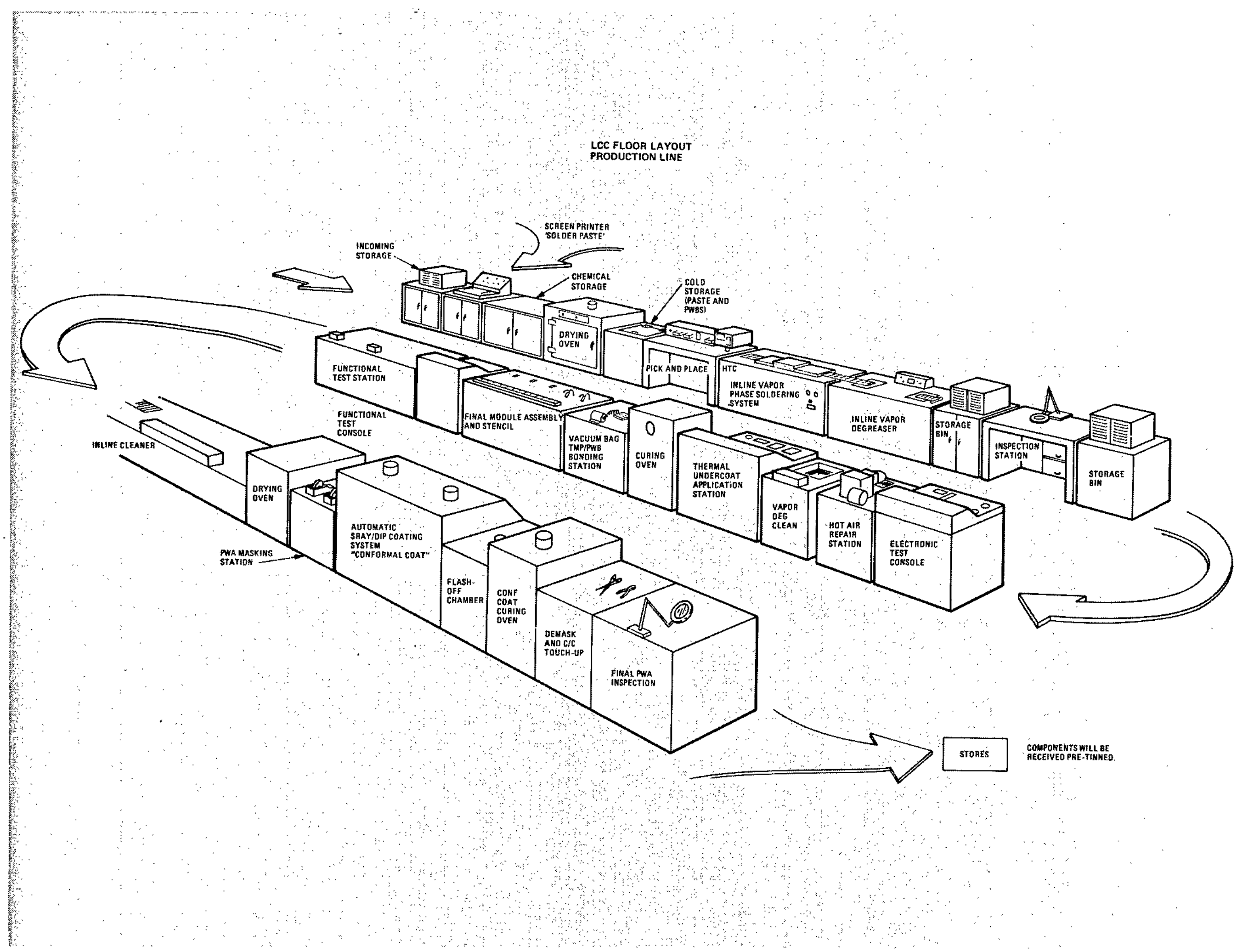


Figure 15

modified polyimide/Kevlar, and copper-clad Invar were directly related to the survival life of the joint.

- **Survival life of solder joints is enhanced by closely matching the coefficients of thermal expansion of the leadless chip carrier, printed wiring board, and thermal mounting plate.**

- **Printed wiring boards of modified polyimide/Kevlar can be readily fabricated with the subtractive process.**

- **Leadless chip carriers in high density circuits yield lower overall system costs.**

Table 2

Modified polyimide/Kevlar printed wiring boards for the attachment of surface-mounted leadless components can be readily fabricated with standard printed wiring board processes utilizing existing standard equipment.

Finally, it was indicated that surface mounting of leadless components should result in a significant reduction in process time because of the automated placement and assembly of the components.

- **Recommendations**—Hughes Aircraft recommendations are summarized in Table 3. To facilitate the use of modified polyimide/Kevlar for military use, the industry and military sectors should revise MIL-P-13949 to allow the use of this material as a substrate. Presently, this specification covers only the epoxy-glass and polyimide-glass materials and no military specification is available for the modified polyimide/Kevlar.

An improved technique for the inspection of the solder joints is needed because existing visual inspection of the large number of joints per leadless chip carrier and the limited access to the solder joint results in early operator fatigue.

Since the fatigue resistance during thermal cycling of the common solder alloys is quite poor, both at ambient and elevated temperatures, consideration should be given to developing an alloy with resistance to grain growth from thermal aging.

- **Revise the military specification, MIL-P-13949, for PWB material to allow the use of the low expansitivity modified polyimide/Kevlar.**

- **Develop better inspection techniques for solder joints.**

- **Develop solder alloys with improved fatigue resistance.**

- **Develop fluxless soldering.**

- **Investigate more efficient modes of thermal management.**

Table 3

The small gap between the leadless chip carrier and the substrate does not allow for easy removal or inspection for residual flux. Additionally, a clean periphery around the joints does not assure the absence of flux contamination beneath the body of the chip carrier. To circumvent these conditions, it is recommended that industry develop a soldering technique free of flux (fluxless soldering).

Since heat fluxes rapidly escalate at the chip and package level with a decrease in hue width and an increase in gate counts, an assessment of the thermal control strategies is necessary. Consideration should be given to metal core boards, flow-through modules, and heat pipes. Metal core printed wiring boards can be utilized as integral heat sinks by drilling holes through the laminate beneath the leadless chip carriers and filling the hole with a conductive media. This procedure allows direct heat conduction from the leadless component to the metal core and thence to the heat exchanger. Both flow-through modules and heat pipes with populated printed wiring boards bonded to both sides of the structure are an effective means of thermal management.

High Conductivity, Transparency

RF and Laser Hardening of Missile Domes

DR. DAVID L. JONES is Manager of the Countermeasure/Counter Countermeasure Office of the Guidance Control Directorate, Army Missile Laboratory, U.S. Army Missile Command. He has worked the past 18 years on countermeasure projects designed to provide greater survivability of Army missiles in a countermeasure environment. Prior to his joining the Missile Command, he worked several years for Honeywell Aeronauticall Division and Sperry Space Support Group. He is a member of the Old Crow's Countermeasure Society and is active in MICOM manufacturing technology projects. He received his B.S. from East Tennessee State, his MBA from Alabama A&M, and his Ph.D. from Southeastern Institute of Technology.

Photograph
Unavailable

Reactive sputtering of indium tin oxide (ITO) transparent conductive coatings on the iside of U.S. Army Missile domes now is a viable approach to rf hardening of laser-guided missiles. This major conclusion was reached as a result of a manufacturing methods and technology project initiated by the U.S. Army Missile Command to adapt the fusion laser coatings and coating process to the case of heat-sensitive plastics in hemispherical or conical shapes.

Battelle's Pacific Northwest Laboratory conducted the two-year project to demonstrate optical coatings, production coating equipment, and a production process for rf and laser hardening plastic missile domes used by MICOM. The primary objective of the project was transparent rf shielding based on indium tin oxide for the Army's Hellfire (polycarbonate plastic) and Copperhead (polysulfone plastic) laser-guided missile domes. Specific coating property goals included electrical sheet resistance, dome transmission, rf attenuation and adhesion. The coating equipment and processing were additionally required to permit application of other coating materials such as SiO_2 onto the same plastics for transmission enhancement, abrasion resistance, or wavelength filtering. The most challenging aspect of the project was the achievement of high electrical conductivity and optical transmission for coatings on curved plastic surfaces at lower deposition temperatures.

Battelle's achievement of high resistance to laser-induced damage in transparent conductive ITO coatings for fusion laser applications had suggested their use for both rf and laser hardening of plastic domes for laser-guided missiles and munitions. Of particular interest were the Army's missiles which are guided by radiation from Nd:YAG lasers in a wavelength falling in the region of high transparency. A single layer with the proper conductivity could provide rf shielding when the missile dome was electrically connected to the metal missile body. A multilayer interference filter, one layer of which is ITO, could provide both rf and laser hardening of the missile seeker simultaneously. The transparency of the ITO would allow hardening with minimal impact on the domes' transmission.

Batch Production Provided

Chronologically, the project consisted in scope of

- Assembly of a small coating system for coating and process development using one dome at a time

NOTE: This manufacturing technology project that was conducted by Battelle's Northwest Laboratories was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The MICOM Point of Contact for more information is Mr. David Jones, (205) 876-8331.

- Design and construction of a large batch production chamber for coating thirteen domes simultaneously with automation and improved instrumentation and control.

The smaller chamber was used to demonstrate that reactive magnetron sputtering could produce ITO coatings with the required properties on temperature sensitive substrates. Hundreds of domes were coated and tested both at Battelle and MICOM to optimize the process and to develop specifications for later production coating.

The larger chamber was used to demonstrate production-scale implementation of the process at affordable costs. Other important project tasks included:

(1) Development of procedures for dome cleaning before coating

(2) Several techniques for applying metal electrodes or or contacts to the ITO coatings

(3) A process for fabricating the In/Sn sources (targets) used in the coating process and

(4) Techhiques for sheet resistance, spectral transmission, and thickness uniformity measurements on missile domes.

Hellfire domes have been hardened to greater than 30 dB shielding at the important rf frequencies with a low loss in transmission. Copperhead domes have also been coated with similar or better ITO coatings. The adherence of the coating to the plastics has been measured to be several thousand psi. Thirteen domes can be coated in 180 minutes in a vacuum deposition process involving sputtering of In/Sn metal in a reactive atmosphere. The resulting coating cost is thus about $44 per dome. Electrical contact of the ITO to the missile body requires application of a metal electrode to the threaded region of the dome. Plasma sprayed Zn, which is applied in a few minutes using a hand-held gun, works well on Hellfire domes. Some air sprayed Ag paints work equally well. Multilayer coatings of ITO and a second suitable material such as SiO_2 appear to be possible, suggesting simultaneous laser hardening by interference filtering.

Logical and orderly production implementation of the ITO coatings and processes included the following major steps:

- Environmental testing to confirm long expected coating lifetime when exposed to humidity, temperature cycling, shock, etc.

- Field testing on fired missiles

- Interaction of Battelle staff with the selected production coating contractor to ensure maximum benefit from the project.

Wider Applications Foreseen

The main conclusions of the project were (1) the technical feasibility of achieving significant rf shielding with transparent coatings less than a micron thick is unquestionably established, (2) ITO coatings can be applied to both Hellfire and Copperhead domes, (3) 30 dB rf attenuation is achieved by these coatings for frequencies in the critical range, (4) demonstrated batch production coating techniques can be used in semiautomated fashion for coating large numbers of domes, (5) batch production ITO coating costs are estimated to be about $44 per dome, (6) suitable demonstrated electrodes include plasma-sprayed Zn and air-sprayed Ag epoxy paint, and (7) SiO_2 coatings can be deposited in the same system for transmission enhancement, abrasion resistance, or wavelength filtering. The coatings and processes further appear to be applicable to virtually any electromagnetic window or dome (crystal, glass or plastic) in flat or near-hemispherical shape.

Other important project accomplishments included (1) the development of many processing procedures needed for production dome coating and evaluation such as ITO deposition parameter optimization, pre-coating dome cleaning, In/Sn source casting, and coating characterization on a curved surface, (2) the documentation of coating specifications, process and operation instructions, and equipment details, and (3) the delivery of seventy-six coated domes for evaluation by Army agencies such as MICOM and the Office of Missile Electronic Warfare (OMEW) or to the Army's dome contractor, Martin Marietta-Orlando.

A related subcontract conducted by Battelle's Columbus Laboratories demonstrated alternate approaches to transparent rf shielding for plastic missile domes. Manufacturing methods were developed for applying metallic grids or screens to the plastic domes. Two approaches demonstrated include a free-standing grid made by a modified flexible circuit board technique and a thin-film grid vapor deposited through a fabricated mask.

ITO Coatings Offer Benefits

Of all transparent conductive coatings for use in the visible and near-infrared spectral regions, the indium-tin oxide solid solution system has received the most attention to date because it simultaneously offers the highest conductivity and transmission. Maximum conductivity or minimum resistivity is usually obtained with some of the Sn replacing In substitutionally and serving as a donor impurity. Oxygen vacancies also make a major contribution to the electron carrier concentration in ITO coatings. For a given Sn content, control of oxygen deviations

from exact stoichiometry allows sensitive control of ITO conductivity.

The electrical and optical properties of the semiconductor ITO are intimately related. Generally speaking, there is a tradeoff between high optical transmission and low electrical resistivity. In addition, variation of the electron carrier concentration over several orders of magnitude, which accompanies resistivity changes, has significant effects on both the short wavelength and long wavelength transmission.

Figure 1 shows the wavelength dependence from 0.2 to 2.6 microns of the external transmittance of three ITO coatings with widely different electrical resistivities. Also shown is the transmission curve for a bare fused silica substrate. The two lower resistivity coatings are 0.63 microns thick. The high resistivity coating is 0.30 microns thick. A resistivity of 5×10^{-4} Ohm-cm is very close to the minimum value attainable for ITO. A value of 1 Ohm-cm corresponds to a coating which is nearly completely oxidized. Hence, the coatings of Figure 1 represent extremes which clearly illustrate the differences between highly conducting and semi-conducting (or insulating) coatings.

Note that all three coatings exhibit a short wavelength absorption edge in the ultraviolet spectral region due to optically induced interband electronic transitions. In general, fully oxidized ITO has an absorption edge of about 0.35 microns, which shifts to longer wavelengths near 0.40 microns as absorbing oxygen vacancies are introduced to lower the resistivity. For very high oxygen vacancy levels, the absorption edge shifts back to shorter wavelengths, as shown in Figure 1, due to a Fermi level increase caused by the very high electron concentration. The latter shift is known as the Burstein effect.

The interference pattern in the transmission curves for the coated substrates is due to constructive and destructive interference of light reflected from the air-coating and coating-substrate interfaces. Knowing the refractive index of the substrate, the index of the coating can be deduced at various wavelengths from the amplitude of the interference pattern. For the two higher resistivity coatings of Figure 1, the index is 1.80 near 1 micron and 1.85 near 0.55 micron. The refractive index is dependent on deposition conditions, however. For the low resistivity coating of Figure 1, the index cannot be deduced accurately from the interference pattern amplitude because of absorption due to the large oxygen vacancy concentration. The percent absorption loss is roughly the difference between the transmission of the coated substrate and the bare substrate near the maxima in the interference pattern.

The long wavelength absorption edge also depends on the coating resistivity, as shown in Figure 1. For the low resistivity coating, the transmission cutoff for wavelengths greater than 1 micron is clearly evident. For the high resistivity coating, little loss is detectable even near 2.6 microns. The long wavelength absorption edge in ITO is caused by metal-like free-carrier absorption which is responsible for an increase in the reflectivity and a concomitant transmission decrease. The increase in the reflectivity which accompanies the transmission decrease is shown very clearly for a highly conductive coating in Figure 2. Note that the coating absorption, defined as 100%-transmission-reflection, exhibits a peak or resonance near 1.65 micron. This long wavelength absorption edge or "plasma frequency" shifts to shorter wavelengths with decreasing resistivity. For a resistivity of 5×10^{-4} Ohm-cm, the edge is between 1 and 2 microns as shown in

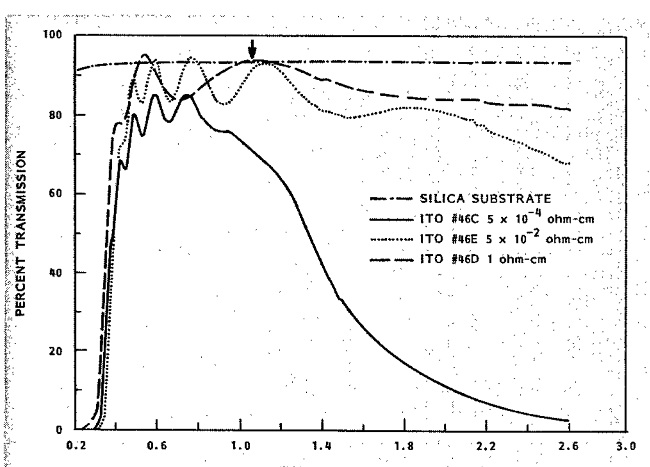


Figure 1

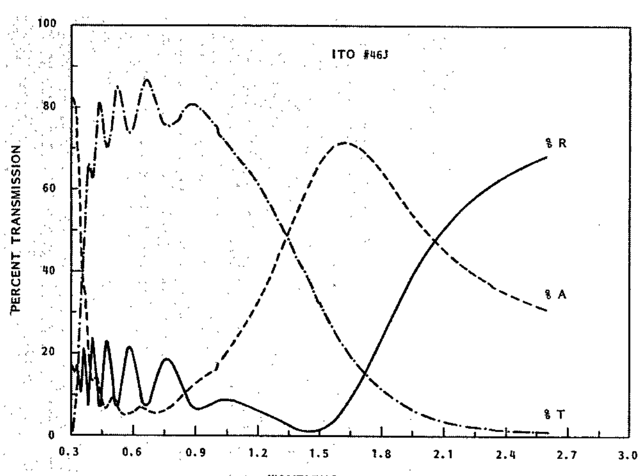


Figure 2

Figure 2. For 1 Ohm-cm resistivity, the edge is in the far infrared.

The optimum resistivity for low sheet resistance and high transmission near 1.06 microns is about .003 Ohm-cm. Thus, for a sheet resistance goal of 10 Ohms/square, the coating thickness must be approximately 1 micron. From Figures 1 and 2, it can be estimated that a coating with 10 Ohms/square resistance and a thickness of 1 micron will have a transmission loss of about 10% at 1.06 micron wavelength.

Coating Approach

Low-cost mass production coating of plastic domes with indium-tin oxide requires a coating process which gives (1) high deposition rates, (2) little substrate heating, (3) precise deposition control, and (4) uniform thickness over an approximately hemispherical shape. The coating process chosen for this work is reactive manetron sputtering with a "point-like" source. Sputtering processes in general give precise deposition control. Magnetron sputtering yields high deposition rates and little substrate heating by using a permanent magnet behind the source to efficiently ionize the sputtering gas while confining the plasma to the source region so that little substrate bombardment occurs. The small diameter or "point-like" source was chosen because it produces an approximately hemispherical distribution of sputtered material which will uniformly coat an approximately hemispherical substrate or an approximately hemispherical array of substrates.

Reactive Sputtering

Deposition of ITO coatings by reactive sputtering requires an In/Sn metal source mounted on a dc electrode inside of a vacuum chamber. Sputtering is accomplished by introducing a low pressure of an inert gas such as argon while applying a negative dc voltage to the source. A sustained discharge results and a plasma of Ar positive ions and electrons forms near the source. Attraction of Ar positive ions to the negatively biased source leads to bombardment, which in turn results in sputtering or atom-by-atom removal of material from the In/Sn source and subsequent travel to the substrate with kinetic energy in the range of 5 to 10 eV when leaving the source. Addition of a reactive gas such as oxygen to the Ar permits deposition of the oxides of the source metal by reaction with the metal atoms as they travel to the substrate or while on the substrate surface. Careful balancing of the sputtering rate for In/Sn against the introduction rate for oxygen results in the oxide composition which is both transparent and conductive.

Batch Coating System

Two versions of a small coating system were designed and built during the first year's work. The larger batch-production coating system consists of a large vacuum chamber, an automatic pumping station, and complete automatic instrumentation for precise reactive dc magnetron sputter coating. The system is shown schematically in Figure 3. The system handles thirteen Hellfire domes at a time and can be cycled two times in an eight-hour shift. All major deposition parameters are controlled by state-of-the-art digital closed-loop feedback controls. Coating thickness, dome transmission, and approximate level of oxidation are additionally monitored optically to help achieve the required coating properties and for precise end-point control.

The batch-production coating system is built around a custom made box-type vacuum chamber. The chamber is similar to many used by the optical coating industry. Vacuum-tight access through the chamber walls is pro-

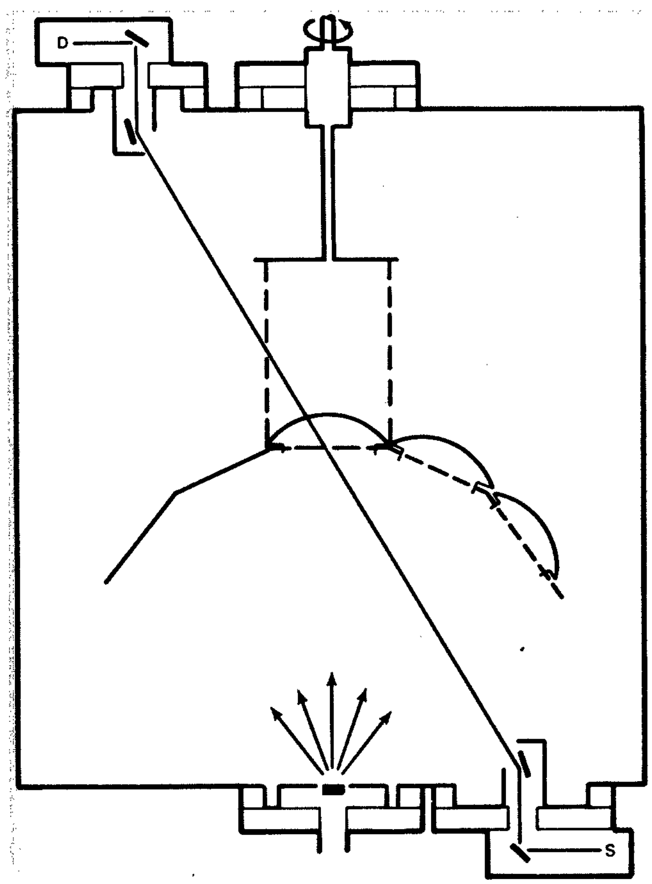


Figure 3

vided by numerous flanges. A full-size door with a captured O-ring seal gives ample access thru the front wall of the chamber for system component assembly and loading/unloading of substrates. The box chamber is connected through a goose-neck pumping stack to a conventional oil-diffusion pumping station with a liquid nitrogen cold trap and a mechanical roughing/backing pump. The pumping station is equipped with automatic valve control using both thermocouple and ion gauge instrumentation. The fully loaded chamber (including thirteen domes) is evacuated typically with the roughing pump in about 8 minutes, and further evacuated with the diffusion about 30 additional minutes.

The substrate holder visible in Figure 4 is a simple carousel suspended from the chamber top through a flange and rotated with a 12-rpm motor drive and a rotating feedthrough. The substrate holder accommodates thirteen domes in a closed-packed co-axial arrangement. The holder is constructed from welded pieces of stainless steel rod with spaces between the rods matched to the outer thread diameter of the dome for simple and secure loading. The overall shape of the substrate holder is designed to conform to a surface of constant deposition rate determined in previous chamber profiling experiments.

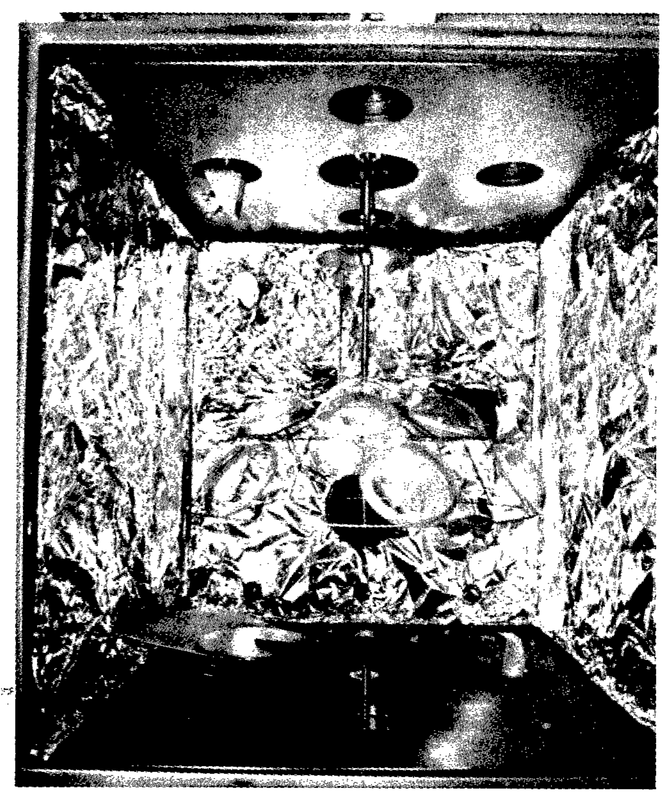


Figure 4

A rotatable shutter made of stainless steel plate welded to a stainless steel rod enters through a differentially pumped double O-ring vacuum seal on a flange bolted to the bottom of the chamber. The shutter allows cleaning, surface preconditioning, and/or stabilizing of the source before coating. The shutter is visible in Figure 4.

Three windows on the chamber door allow visual observation of the coating process, using the light of the glow discharge or an internally mounted incandescent light bulb.

The optical monitor beam-directing hardware is pictured in Figure 4, and the light path is indicated schematically in Figure 3. The light source, chopper, lens, and a 90-degree turning mirror mount on a flange on the chamber bottom. The wavelength filter, lens, detector, and a 90-degree turning mirror mount on a flange on the chamber top. Gimbaled periscopes with 30-degree turning mirrors are mounted on the bottom and top of the chamber to direct the light beam from the chamber bottom to the top through the top dome in the substrate holder. Use of the optical monitor to obtain the correct ITO coating thickness as well as instantaneous feedback on the coating properties is illustrated schematically in Figure 5.

Numerous other ports on the chamber are used for introducing argon and oxygen sputtering gases and for thermocouple gauges, ion gauges, and capacitance manometers. Argon and oxygen gases are continuously bled into the chamber during deposition through a series of valves and flow meters that provide either manual or closed-loop, automatic feedback flow control. Manual control is provided by precision needle valves which allow adjustment of the individual argon and oxygen flows from the regulated storage bottles to the chamber in flow increments. Automatic control is provided by flow ratio controller, electronic valves, and mass flow meters. The sputtering gas pressure is monitored with a capacitance manometer and is also displayed digitally by the flow ratio controller.

The power supply for the magnetron sources is a constant-current dc supply which is connected to either of the two sputtering sources through a relay-type switch. For precise manual control, the current adjust on the supply was changed from a 1-turn to a 10-turn potentiometer, and digital meters were added for precise reading of the source voltage and current. For automatic sputtering voltage control, a digital controller is used in conjunction with a stepper-motor-driven variable orifice located in the pumping station between the diffusion pump and cold trap. The digital controller is programmed to maintain constant voltage to the source by opening and closing the variable orifice as needed to adjust the sputtering gas pressure.

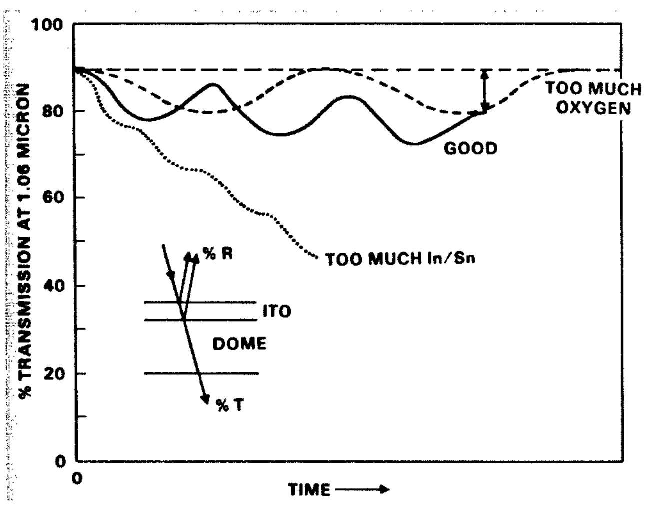


Figure 5

Sputtering Source Fabrication

For mass production coating of large quantities of domes, a supply of In/Sn sputtering sources is needed. New sources can be fabricated simply by casting into an Al mold on a conventional laboratory hot plate. The mold is machined to produce the desired target shape and size, or can be purchased. In and Sn in shot, wire, or rod form are mixed in a beaker. The beaker is placed on a hot plate and heated until all the shot melts. After stirring, the molten mixture is poured into the Al mold, which is also preheated on the hot plate. The casting and mold are then allowed to cool.

Deposition Parameters

Stoichiometric indium oxide is a transparent insulator. Adding tin as a substitutional dopant reduces its resistivity. To achieve resistivities required to meet the property goal for this project, oxygen vacancies were introduced by deliberately depositing coatings which were slightly deficient in oxygen. Since too large an oxygen deficiency will result in a metallic nontransparent coating and since too little an oxygen deficiency will result in a resistive coating, the number of oxygen vacancies must be precisely controlled.

Control of the oxygen vacancy level in reactive sputtering is achieved by balancing the rate at which In/Sn metal is sputtered from the source against the rate at which oxygen is introduced into the chamber to react with the In/Sn. The rate at which In/Sn is sputtered is controlled by two parameters: the source voltage and the source current. The rate at which oxygen is introduced is the flow. Hence, the three principal deposition parameters which must be controlled are source voltage, source current, and gas flow. Each of the three can be controlled precisely with closed-loop feedback instrumentation.

With these concepts in mind, strategy for controlling the oxygen vacancy level in ITO is easily seen to be an iterative process. First, a coating is made with the current, voltage, and oxygen flow set at values expected to yield transparent conductive ITO based on previous values used, and the coating transmission and sheet resistance are measured. If the coating is highly transparent and resistive, it is too fully oxidized. Thus, in the next deposition the current or voltage must be raised to increase the metal content relative to oxygen, or the oxygen flow must be lowered. If the first coating is metallic or dark, the current or voltage must be dropped or the oxygen flow increased. This process is repeated until the desired coating properties are achieved and the optimum deposition conditions are determined.

Systematic Tuning

Systematic tuning of deposition parameters in an iterative process to achieve the optimum tradeoff between transmission and resistance is illustrated in Figure 6. By systematically stepping through oxygen flows, a flow which produces high transmission and low resistance can be found. Note in the top curve that, at high oxygen flows, the ITO is transparent and transmission approaches that of the bare dome. At lower flows, the coatings are darker and lower in transmission. The sheet resistance curve at the bottom shows a minimum near the transition from transparent to opaque.

An alternate approach to tuning the deposition parameters is to fix the current and oxygen flow while varying the voltage, as shown in Figure 7. Note in the upper curve that low voltages result in high transmission, because at these voltages In/Sn is sputtered more slowly and is fully oxidized by the oxygen flow. At higher voltages, In/Sn is sputtered more rapidly than it can be fully oxidized and the ITO becomes dark and even metallic. The lower curve again shows that the sheet resistance exhibits a minimum near the transition from transparent to opaque ITO.

Systematic tuning data are shown in Figure 8. Note that the higher current requires a higher voltage for near optimum tuning. Also note that in Figure 8 the range of oxygen flows selected is broader than that of Figure 6, so that the ITO ranges from all metal at low flows to fully oxidized at higher flows. The resistance again exhibits a minimum near the transition point.

During the Sn content optimization work, it was discovered that the optimum oxygen flow was dependent on the source Sn content. The general dependence is shown in Figure 9.

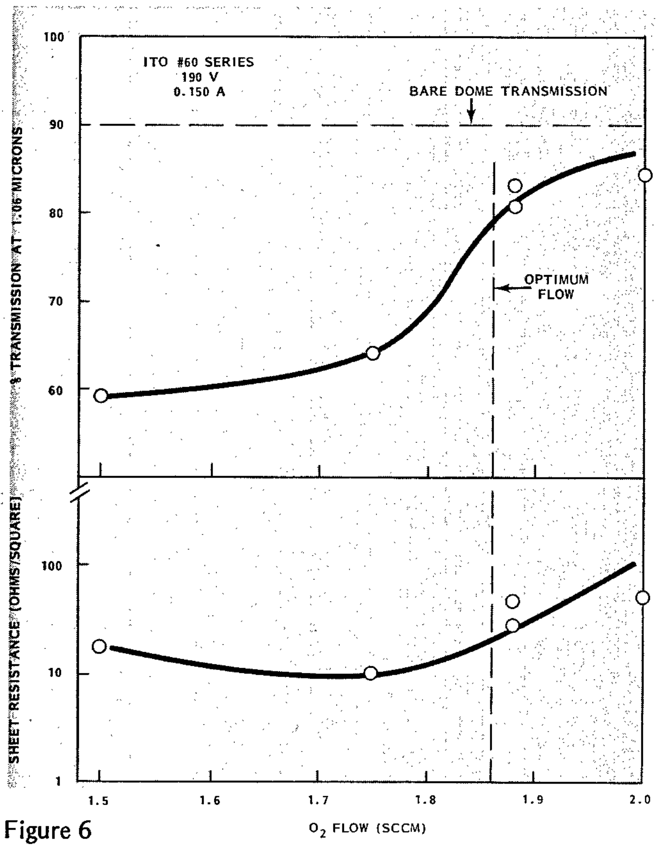


Figure 6

Parameter Tuning Aids

Achievement of the optimum conductivity and transmission for ITO coatings deposited without substrate heating requires careful tuning of the deposition parameters. In addition to the systematic plotting methods described in the previous section, several aids exist for deciding which direction to vary parameters (increase or decrease) and how much to change the parameters (increment). The aids range in type from quantitative to qualitative, and should be frequently consulted when conducting a systematic parameter optimization.

Figure 10 describes the first aid. It semiquantitatively displays the ITO coating's visual appearance and sheet resistance in the neighborhood of the optimum tuning point. At the optimum tuning point, clear coatings are obtained. If the coatings contain too much oxygen (sputtering current and voltage too low, or oxygen flow too high), the sheet resistance rises very rapidly and the coatings appear pale green or yellow to the eye. If the coatings contain too much In/Sn (sputtering current and voltage too high, or oxygen flow too low), the sheet resistance rises slowly and the coatings appear tan or brown.

The second aid is to observe after deposition the color of the source inside vertical wall. (See Figure 4). After a deposition at the optimum conditions, the source will appear a dull or matte gray with black and white specks (''salt and pepper'' appearance).

The third aid, shown in Figure 11, is quantitative and is frequently helpful when first setting up the system before any systematic parameter stepping has been attempted. In this method, the source sputters onto the closed shutter with the current fixed at the value usually used, and the pumping orifice is adjusted to give a fixed chamber pressure. The oxygen flow is raised to a point expected to be well above the optimum flow, and the voltage induced on the source is recorded. The oxygen flow is then reduced in appropriate steps. At each step, the orifice is adjusted to maintain the pressure and the source voltage is recorded.

The fourth aid is presently qualitative, but could have great value if the deposition chamber were instrumented for quantitative measurements. When metal-rich coatings are being deposited, the glow region above the source is

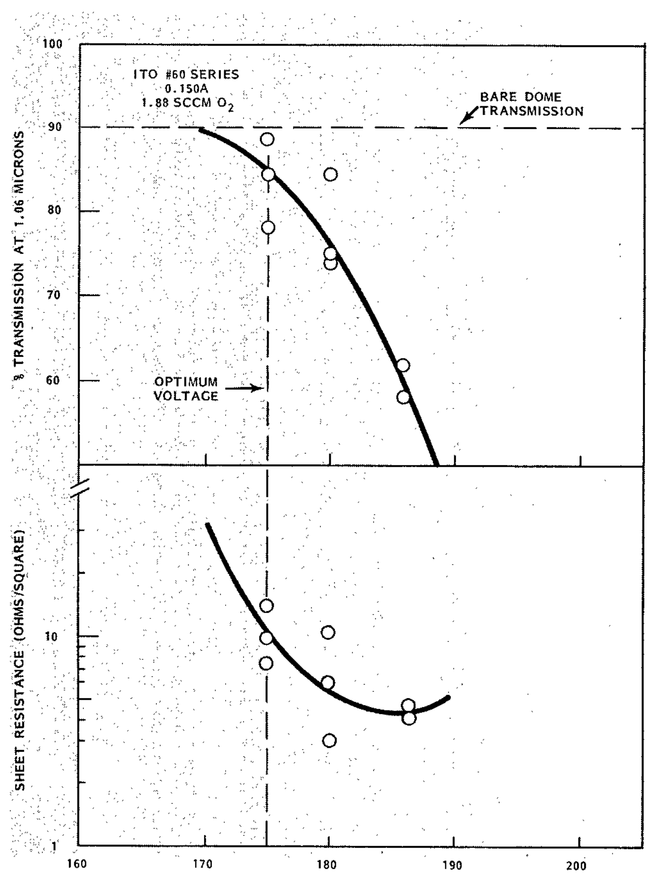


Figure 7

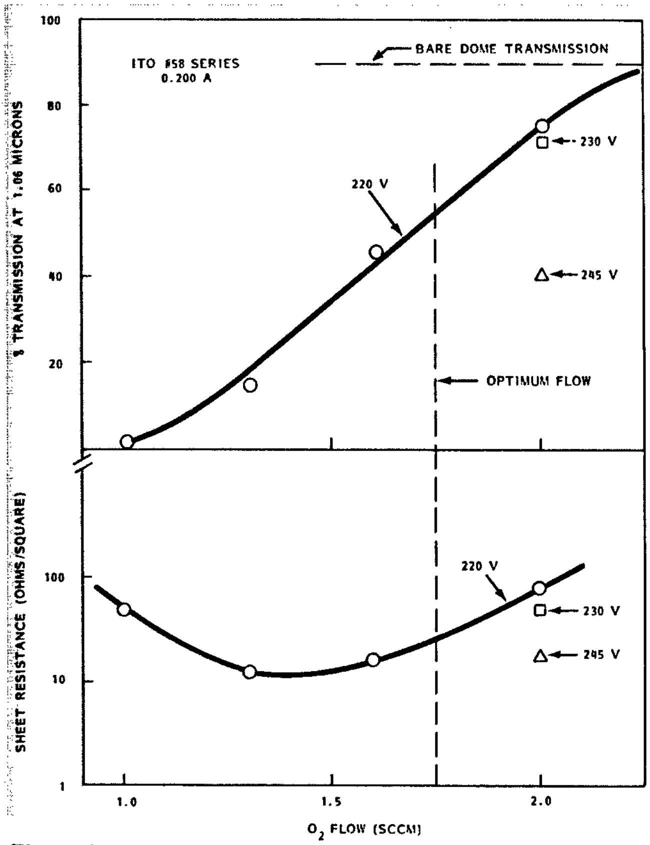


Figure 8

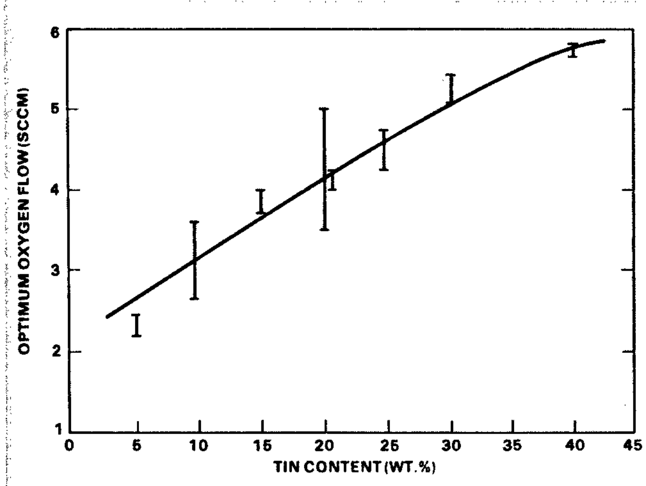


Figure 9

Optical and Electrical Characterization

Reasonably extensive characterization of the optical and electrical properties of hundreds of ITO coatings was necessary to provide guidance in coating optimization and to assess progress toward project property goals. These measurements included the following:

- RF shielding
- Spectral Transmission
- Micron Transmission
- Refractive Index
- Thickness Uniformity
- Sheet Resistance

blue in color. When oxygen-rich coatings are being deposited, the glow region is pink. The optimum tuning point lies between these colors. The difference in colors results from the varying ratios of electronically excited metal, metal-oxygen, and oxygen species in the plasma.

The fifth aid worthy of mention is the optical monitor used in conjunction with Figure 5. Metal-rich coatings sputter rapidly and absorb noticeably with increasing thickness. Fully oxidized coatings sputter slowly with little apparent transmission loss with increasing coating thickness. Optimum ITO coatings lie between these extremes, and can be obtained more frequently if deposition conditions are fine tuned as the coating grows to produce a transmission monitor strip chart similar to that known to result for a good coating run.

Vacuum Heat Treatment Option

An alternative to controlled deposition of ITO as described above is deposition of fully oxidized or stoichiometric ITO followed by vacuum heat treatment to produce the oxygen deficiency required for conductive coatings.

Key Results

Figure 12 is a representative summary of the shielding levels observed for specific domes as a function of ITO sheet resistance for one frequency of importance. Each point plotted is for a separate ITO-coated dome measured on the same day.

Highest rf attenuation is obtained for the lowest sheet resistance, as expected. With increasing sheet resistance, the attenuation decreases, giving effectively no shielding (the bare dome value) for greater resistances.

Figure 13 shows transmission as a function of sheet resistance for the same domes described in Figure 12. The

lower curve marked "average" is the average of transmission measurements made at nine different, uniformly spaced points on each coated dome. The upper curve marked "maximum" is the maximum of the nine values for each dome. The transmission increases monotonically with increasing sheet resistance and approaches the bare dome value for greater resistances. The transmission decrease with decreasing sheet resistance is fundamentally unavoidable: the same electrons which lower the sheet resistance also absorb light.

The different transmissions measured at different points on a dome result primarily from coating thickness differences.

Very recently, a careful study of the influence of Sn content on the properties of ITO revealed that improved transmission and sheet resistance both result for higher Sn content.

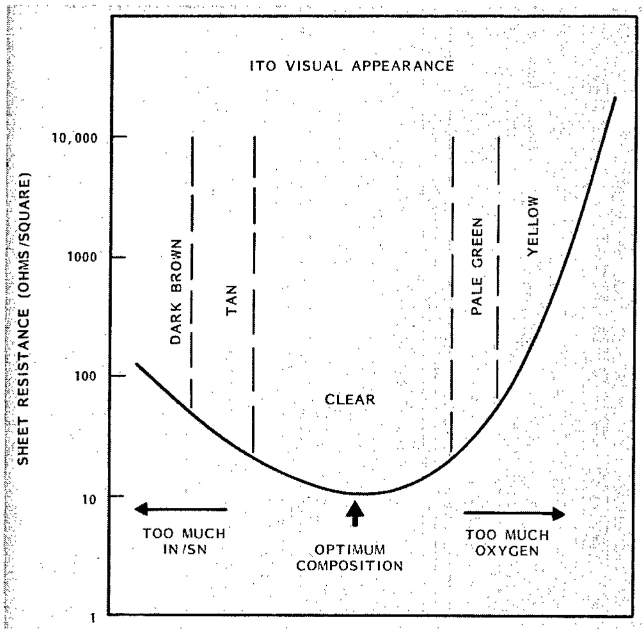


Figure 10

Potential Improvements

For applications requiring higher transmission, two improvements can be made if cost/benefit considerations warrant.

First, additional transmission can be achieved, according to calculations, by adding a low index coating layer such as SiO2 or MgF2 on top of the ITO to make a two-layer antireflection coating for one side of the plastic. (The transmission loss of the plastic is primarily Fresnel reflection).

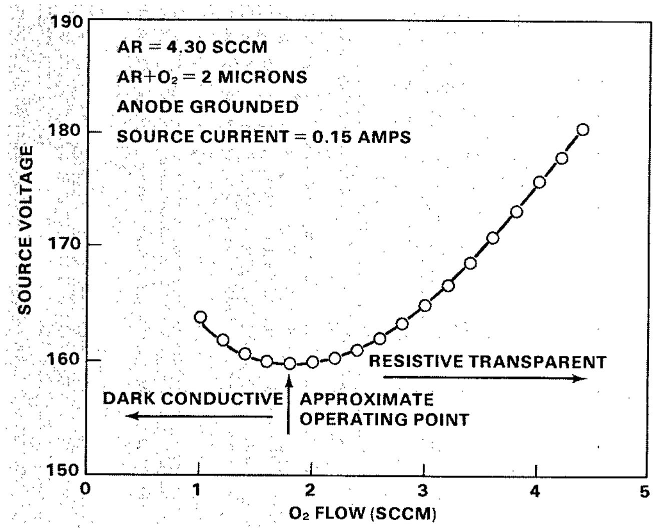


Figure 11

Second, additional transmission can be achieved by adding a single low-index layer of appropriate thickness to the outside of the dome. SiO2 and MgF2 are again promising candidates. Use of the SiO2, which is much harder than polycarbonate, may simultaneously improve the scratch and abrasion resistance of the polycarbonate domes.

All coated domes made in the project were measured for sheet resistance, spectral transmission, coating thickness, and transmission. Domes coated in the second year were, in addition, characterized for sheet resistance uniformity and transmission uniformity by measurements at a minimum of nine different points on each dome. Adherence to polysulfone and polycarbonate was measured on selected samples. Domes were then sent to MICOM for rf shielding evaluation.

Electrode Selection and Application

A metal electrode is required to ensure electrical contact between the ITO and the missile body. The coil housing to which certain coated domes are threaded during missile assembly is conductive on its exterior surface and contacts the outer flat surface of the domes. Since the ITO coatings are applied only to the inside of the domes, a metal electrode is needed to contact the ITO with this outer flat surface. Contact requires continuity across the dome threads. For some domes, the threads are inside the dome and the entire coil housing is metal.

The electrode problem and the electrode geometries selected to solve the problem are illustrated in Figures 14 and 15 for polycarbonate and polysulfone domes. Each dome is first coated on the inside with ITO.

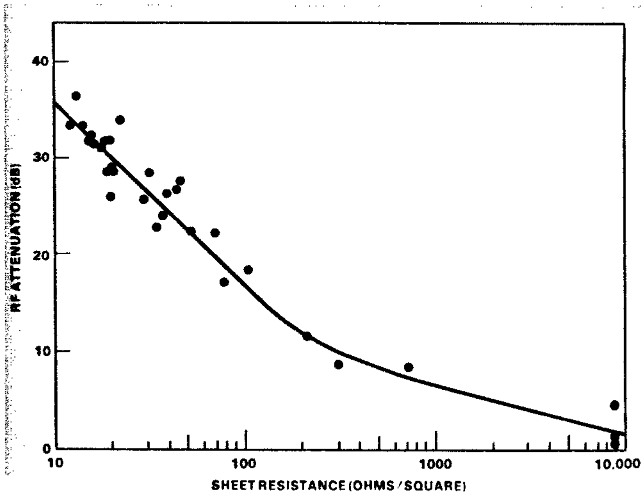


Figure 12

To electrically mate with the conductive coil housing, the Hellfire electrode must extend and be electrically continuous across the outermost flange surface, through the threads, across the bottom flat surface, and up inside the dome to the beginning of the optical surface. The thickness of the electrode should not be more than standard machining tolerances (a few 0.001 inch) to avoid problems when the dome is threaded onto the coil housing. If the coil housing were made of metal or conductively coated across its top gasket groove, it might not be necessary to coat the threads of these domes, thus greatly simplifying electrode application.

The polysulfone dome electrode requires continuity only through the threads so that the ITO coating above the threads contacts the all metal coil housing when the dome is screwed into place. However, some additional contact may be achieved by extending the metal below the threads and across the dome bottom surface. For additional rf shielding, the electrode on this dome can be extended up the interior surface to the optical surface.

Selection Criteria

Two properties appear to be important to the performance of a dome electrode material. For good electrical contact and good rf shielding, low electrical resistivity is imperative. To resist galling in the threads after screwing on and off several times, hardness or abrasion resistance also appears to be an important electrode property.

The process of applying the electrode similarly must meet several criteria. First, it should be low in cost compared to the ITO coating. Second, it must be compatible with chemically sensitive and temperature sensitive plastic dome materials. Third, it must readily permit coating of complex geometries such as the threads and both inside and outside surfaces of the dome.

Four materials and four different processes were evaluated in the project. The processes include two spraying techniques (plasma spraying of Zn and air spraying of Ag paints), one dip technique (electroless Ni plating), and one vacuum metallization technique (sputtered Ni). The spray techniques worked the best, and appear to meet all the process criteria listed above. Electrodes made by these processes further performed well in rf sheilding tests conducted at MICOM. The dip technique produced poor adhesion due to chemical incompatibility. The vacuum technique could not produce continuous metallization across the threads as expected from its "line-of-sight" deposition nature.

Plasma Sprayed Zn Electrode

Plasma spraying is a very rapid, low cost method for applying a Zn electrode to plastic. Zn is sprayed in fine molten droplet form when it is controllably introduced as a powder into a stream of ionized compressed Ar/He passed through an electric discharge gun. With this technique, the electrode on the polycarbonate domes was applied to a thickness of 0.001 to 0.002 inch inside and outside of the domes in about 3 to 6 seconds with the dome spinning on a rotating table. The setup is shown in Figure 16. A polycarbonate plug was inserted in the dome and held in place with simple tension fasteners to prevent coating the optical surface.

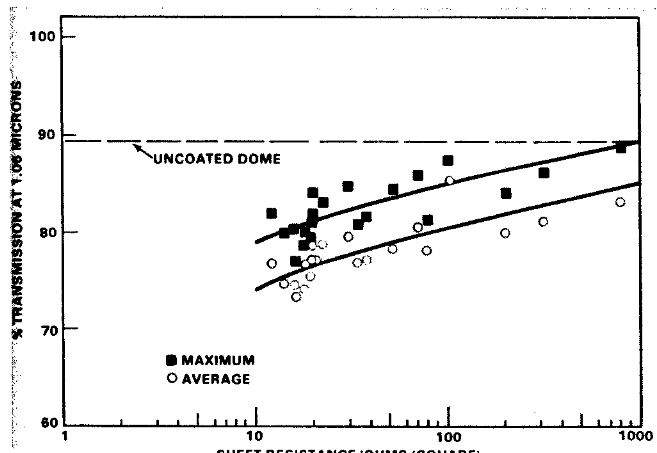


Figure 13

Air Sprayed Ag Paint Electrodes

The paint spraying process is similar in many respects to the plasma spraying approach described in the previous paragraphs. The dome is again mounted on a rotating table and the electrode is deposited to a thickness of 0.002 inch using a hand held spray gun, as shown in Figure 17. A polycarbonate plug is again inserted to protect the dome's inside optical surface, but no fasteners are required to hold the plug in place because of the more gentle nature of the paint spray.

Advantages of the paint electrode over the Zn electrode are: (1) much lower initial equipment purchase costs, roughly \$200 vs. \$17,000, (2) elimination of the grit blasting step, which reduces processing costs and eliminates some grit damage to the optical surface of the dome, (3) expected electrochemical compatibility with the silver impregnated O-ring used on the mating missile coil housing, and (4) low particulate generation.

Disadvantages of the paint electrode over the Zn electrode are: (1) longer processing times including spraying, double coating, time between coats, and curing at elevated temperatures, (2) higher sheet resistance for the same thickness, (3) inconsistent sheet resistance results, and (4) chemical incompatibility between the paint thinner and polycarbonate or polysulfone. Key to the success of the paint spray approach for the Hellfire thread region is a highly conductive and abrasion resistant paint.

Electroless Ni Electrodes

Electroless Ni plating was investigated briefly as a potentially low cost technique for coating threads by submersion in a coating bath. Electroless Ni plating is the catalytic reduction of Ni ions in an aqueous solution of hypophosphite ions. The Ni reduction takes place on the surface of the catalyst.

Sputtered Ni Electrodes

Ni in smooth, hard, shiny and conductive form is easily deposited by sputtering on many substrates, including plastics. Ni coating of missile dome electrodes by sputtering, however, is difficult because the threads are not accessible to line-of-sight deposition. Ni electrodes were attempted on several domes of each type by sputtering so that rf shielding tests could be carried out on the ITO coatings. Deposition was made at much higher sputtering gas pressures than normally used so that collisions of sputtered Ni atoms with Ar atoms might scatter Ni into thread regions not accessible to line-of-sight incidence. This approach appeared to work in that the threaded area was

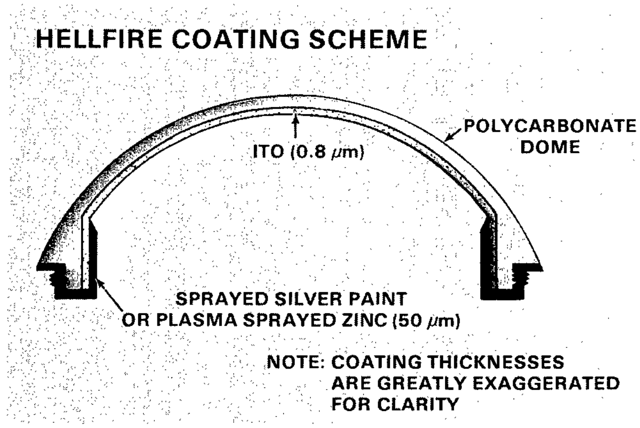


Figure 14

visibly coated and dc resistance measurements across the threads indicated only a few Ohms. However, sputtering at high gas pressures is impractically slow, and the Ni in the threads appears to wear poorly when threaded to an unthreaded from the coil housing several times, so that other contacts should be sought.

Dome Cleaning and Precoating Preparation

Many cleaning solvents and procedures were examined throughout the first year of the program to (1) remove fingerprints and other grease, (2) maximize coating adhesion, and (3) avoid "water spots" left on the dome after drying. The essence of the problem is that both polycarbonate and polysulfone degrade rapidly (explosively) in all common laboratory degreasing solvents such as acetone, trichloroethylene, and benzene. Weaker solvents such as freons and alcohols do not harm the domes, but they do not remove fingerprints, either. An interesting and potentially useful observation was that polysulfone was much easier to clean then polycarbonate. Polysulfone domes appeared to be hydrophobic; aqueous cleaning solutions bead or form drops and roll off the dome when tilted, leaving no water spots.

Acid Etching

In first year work, both polycarbonate and polysulfone appeared to be unaffected by inorganic acids over a period of minutes to several hours at room temperature. Hence, ITO coatings not meeting performance specifications were etched off. After drying, the domes were recoated.

In second year work, it was consistently noted, however, that acid etching caused three problems. First, coating adhesion was diminished. Coatings on re-used domes invariably develop (sometimes weeks after deposition) a network of fine microcracks in a circular region about

halfway down the optical surface from the dome top. The cracking does not appear to affect either transmission or rf shielding, but it may indicate a reduction in expected coating lifetime. Second, transmission of the bare dome drops with exposure to acid. Third, the domes develop a yellow color, indicative of increased absorption by polycarbonate in the blue-green region of the visible range.

The conclusion is that etching in HCl is acceptable for re-use of practice domes, but not for domes which must meet transmission, shelf life, and field life specifications.

Deposition Rates

Typical deposition rates when coating domes one at a time or in batches of thirteen depend on four factors: (1) coating stoichiometry, (2) power applied to the source, (3) source to substrate spacing, and (4) age of the source.

The influence of coating stoichiometry on deposition rate arises from the differences in sputtering yield for metals and oxides. Here, sputtering yield is the number of atoms removed from the source for each incident positive Ar ion.

Deposition rate also depends approximately lineraly on source current, since the source current is the number of ar positive ions incident per second and these same ions produce the sputtering.

Deposition rate varies approximately as the reciprocal of the square of the source-to-substrate spacing, for spacings between 6 and 16 inches. This type of behavior is expected from the point-source nature of the sputtering gun.

Age of the source also influences deposition rate through the development of an increasingly wider and deeper ring erosion pattern. The larger erosion pattern is believed to reduce the amount of sputtering per unit area of source surface so that more oxide forms and lowers the sputtering yield.

Thickness Uniformity

Optical thickness uniformity is important to dome coating performance because it influences both the uniformity of transmission across the dome surface (through interference effects) and the sheet resistance (through geometric effects).

When coating domes one at a time with the optimum source-to-substrate spacings, the top was always thicker than the bottom of the dome's optical surface and the thickness decreased monotonically from top to bottom.

When coating domes in batches of thirteen, thickness uniformities were always better than for the single dome deposition case, but appeared to depend on the age of the source.

COPPERHEAD COATING SCHEME

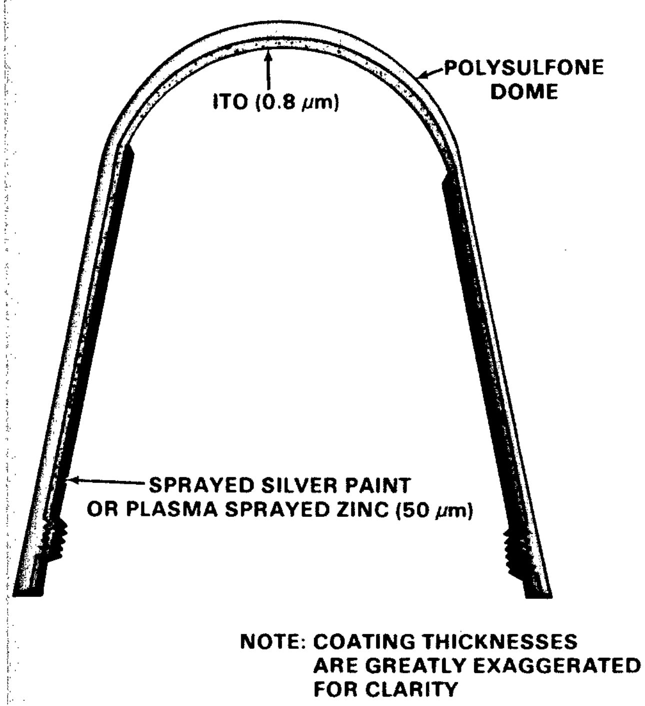


Figure 15

Chamber Rate Profiling

A surface of constant deposition rate is imperative to the proper design of a multidome holder so that all domes receive the same coating thickness.

Using the rotating substrate-holder feedthrough shown in Figure 4, an array of polycarbonate strips is suspended from a rotating threaded rod with a cylindrical spacer. The strips are arranged so that their distance from the source ranges in 1 inch steps, so that each strip causes minimal blocking of the coating flux arriving at the others (spaced angularly). With the entire array rotating, the strips sweep out all useful substrate area from chamber center to edge. A coating deposition is then carried out.

SiO_2 Coatings

Preliminary deposition of SiO_2 coatings was examined to demonstrate that the same equipment and techniques used for ITO could be used to deposit other oxide optical coating materials. SiO_2 is particularly useful because (1) its low refractive index complements the ITO high

index, so that the combination can be used for multilayer antireflection or filtering design and (2) its low refractive index permits its use as a single antireflection coating for the outside of plastic domes. In the latter application, the SiO2 coating is expected to also provide scratch and abrasion resistance for the relatively soft plastics.

Deposition rates are lower for SiO_2 than ITO for comparable source currents and voltages. Deposition proceeds less smoothly as well, with noticeable small arcs occuring near the source surface, especially at higher source power levels. However, the antireflection coating on the dome outside is more than four times thinner than the ITO coating. The SiO_2 thickness required for a two-layer SiO_2/ITO antireflection coating for the dome inside is similarly thin.

Properties

SiO_2 coatings on missile domes exhibited excellent transmission to the eye and lossless transmission throughout the visible and near infrared regions. A 3% transmission enhancement was measured, demonstrating that the single-layer antireflection concept works.

Adhesion of the SiO_2 to the polycarbonate appeared to be excellent. There was no evidence of cracking or peeling. Although no quantitative measurements were attempted, the qualitative hardness of the SiO_2 coatings appeared to be good based on simple scratch tests with a hard, sharp probe.

Cost/Benefit Analysis

The benefit from applying a single ITO coating to a missile dome is rf or EMI shielding protection of about 30 dB while still retaining approximately 90% of the dome transmission. If multilayer coatings are applied, the benefit is transmission enhancement at desired wavelengths or filtering to reject or diminish unwanted wavelengths. If a coating is applied to the dome outside benefits are transmission enhancement and scratch or abrasion resistance for the soft plastic.

Capital Equipment Investment

The exact equipment cost depends upon whether production coating equipment already exists in precisely the form needed, already exists but requires some modification, or does not exist at all and must be purchased and assembled completely. Thus, the capital investment required is bounded by zero (for the first case) and the cost of reproducing part-for-part the batch coating system and electrode spraying equipment demonstrated in this project (for the third case).

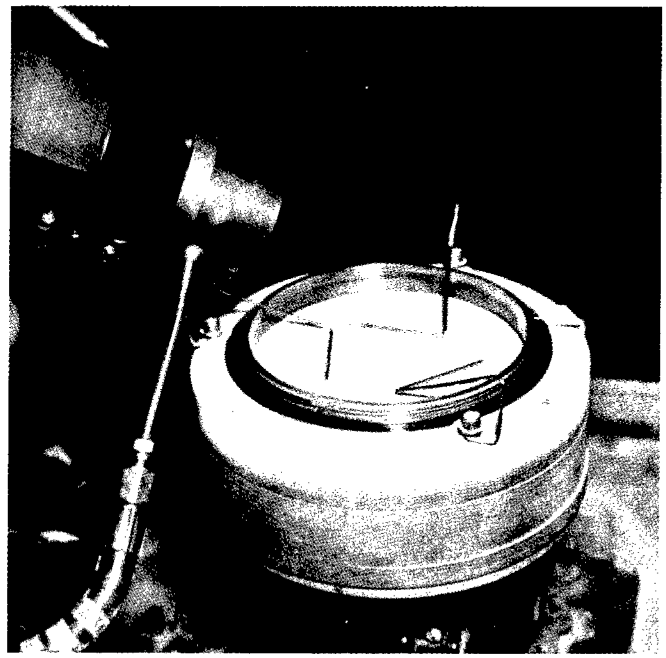


Figure 16

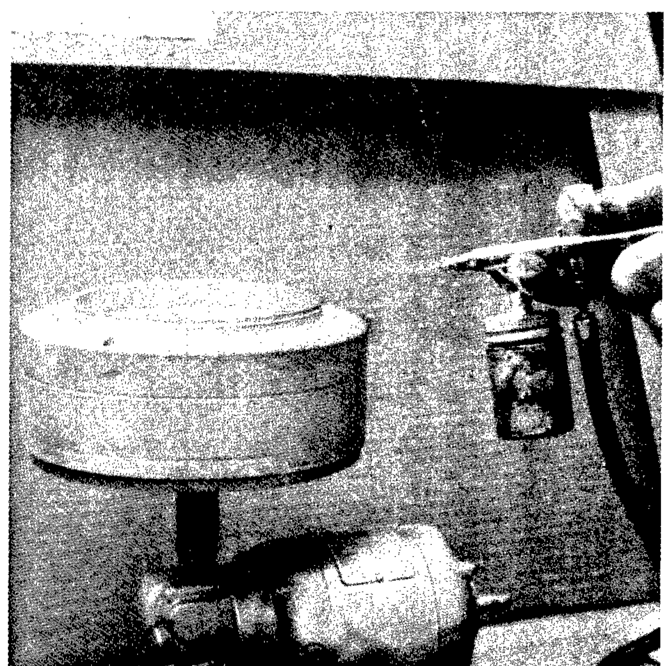


Figure 17

Operation Costs

Much of the coating process is automated and usually only requires one operator for opening the shutter to start the coating run and for shutting off the equipment when the correct thickness is achieved. Hence, the ITO coating process is a single-man operation, and the cost per dome for applying the ITO is determined by the number of domes that can be coated in one day by that operator.

With the batch coating system described in this report, thirteen domes are coated simultaneously and two batches can be coated in one day. Fully burdened costs (including all management and facilities overheads) are expected to be about $70 per hour or $560 per day for an experienced coating system operator. Thus the coating cost per dome is $22, assuming 100% success yield. For 50% coating success yield, the cost is $44.

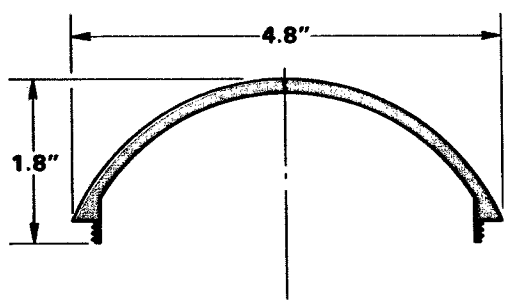


Figure 18

Other Uses of Results

The coating, coating equipment and coating processes demonstrated in this project are expected to be applicable to many other domes and/or windows in Electro-Optic or laser guided missiles or munitions used by the Army, Navy or Air Force. Examples are (1) laser guided bombs, which use seekers very similar to those used in Hellfire and Copperhead missiles, (2) terrain identifying cruise missiles, and (3) camera-guided air to air and air to ground missiles. Other important potential applications include (1) heat rejection and antistatic coatings for plastic aircraft canopies and (2) de-icing and de-fogging coatings for plastic aircraft windows.

Specific commercial applications have not yet been investigated, but the coating and shielding developed here will be useful wherever protection from rf or EMI is needed simultaneously with light transmission at visible or near infrared wavelengths. Possible commercial applications include (1) transparent rf shielding for the windows of household microwave ovens and (2) transparent EMI shielding for the digital display windows of computers, calculators and other instrumentation. De-icing and de-fogging coatings for plastic aircraft windows of commercial aircraft are of course a third application.

Technology Transfer

The contractor for this project can very ably transfer the relevant technology to a suitable commercial entity so that maximum return on the Government's investment is realized. Contractual arrangements for such a technology transfer can be readily made with that contract research organization.

Suitable commercial entities for coating technology transfer include most commercial optical coating firms in the United States. Many of these firms are also familiar with the transparent conductive coatings that have been developed in the project for rf hardening. However, none of these firms have much experience with the reactive sputtering technique required for the unusual substrate materials. Thus, emphasis in the technology transfer would therefore be placed on instruction and familiarization of the selected firm(s) with the sputtering process. Other possible commercial entities to which the technology can be transferred are the firms which presently manufacture domes for the Army.

Four key areas for technology transfer as it relates to this project are (1) coating equipment, (2) personnel training, (3) consultation, and (4) further research or development.

Optional Manufacturing Techniques

In a subcontract with Battelle-Northwest, Battelle's Columbus Laboratories demonstrated a manufacturing method for placing metallic grids on plastic nosecones. Four prototypes and an evaporative mask were delivered for test and evaluation.

This work was based on a Battelle-developed process (now in production) for producing low-cost flexible printed circuits (patterned copper metal on plastic). Battelle-Columbus has a unique facility for this process and, through this effort, has shown that it is applicable to placing patterned metallic structures on the curved surfaces of missile nosecones. A follow-on effort is recommended to optimize the process and determine the manufacturing cost/benefit factors.

The missile nosecone prototypes delivered transmit in the near IR and reflect long wavelength RF. The metallic grid is placed on the inside surface of the nosecone.

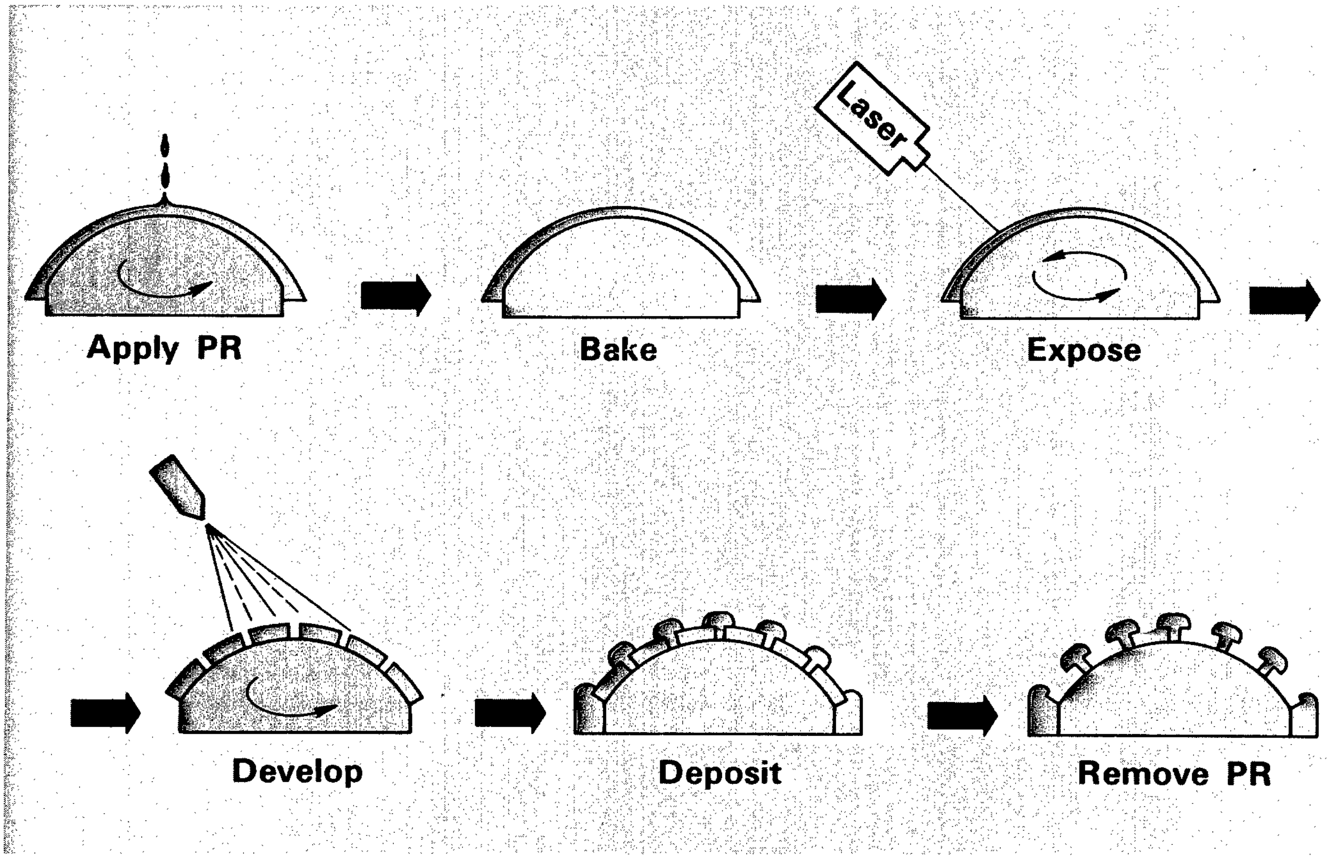


Figure 19

The nosecone geometry is shown in Figure 18. The spherical section is truncated by a radius cylinder and threads are located on the outside of the cylinder. The material is polycarbonate.

Fabrication Process

The grid fabrication process is outlined in Figures 19 and 20. The first step illustrated is the application of positive photoresist to a stainless steel mandrel.

The mandrel has been cut to fit inside a prefabricated polycarbonate nosecone accommodating the metallic grid thickness.

After cleaning the mandrel is spun and the photoresist is applied. Spinning tends to spread the resist to create a uniform coating over the entire surface. The resist is baked dry and after cooling, the mandrel is ready for exposure.

Exposure is accomplished with an ultraviolet laser focused to a spot on the mandrel surface. The mandrel is manipulated, rotated, raised, and rotated in a regular fashion to scan over the predetermined grid pattern. The laboratory apparatus is illustrated in Figure 21. The lens must be indexed slightly with each elevation in order to maintain a constant spot size.

The next step of the fabrication process, as shown in Figure 19, is to develop the photoresist. After exposure the mandrel is placed in a spray booth and spun slowly. Spraying is done at room temperature. Inspection verifies that the lines have cleared, and, after drying, the mandrel is ready for electroplating.

The final step of fabrication is to make provisions to electrically connect the grid to the missile body. The method used in this program was to paint the nosecone rim and threads with conductive epoxy.

Evaporative Grids

A totally different fabrication technique was proven and this optional process remains as a backup technique. The evaporative process is illustrated in Figure 22. A mask is inserted into the nosecone and metal is sputtered or vapor deposited through the open areas of the mask.

The mask was fabricated with the same process described above and in Figures 19 and 20. The mask consists of 50 parallel slots in a thick Ni shell. Fabrication of a square grid requires two vapor depositions; the second after the mask is rotated 90 degrees. One evaporative grid prototype nosecone and the mask were delivered for evaluation.

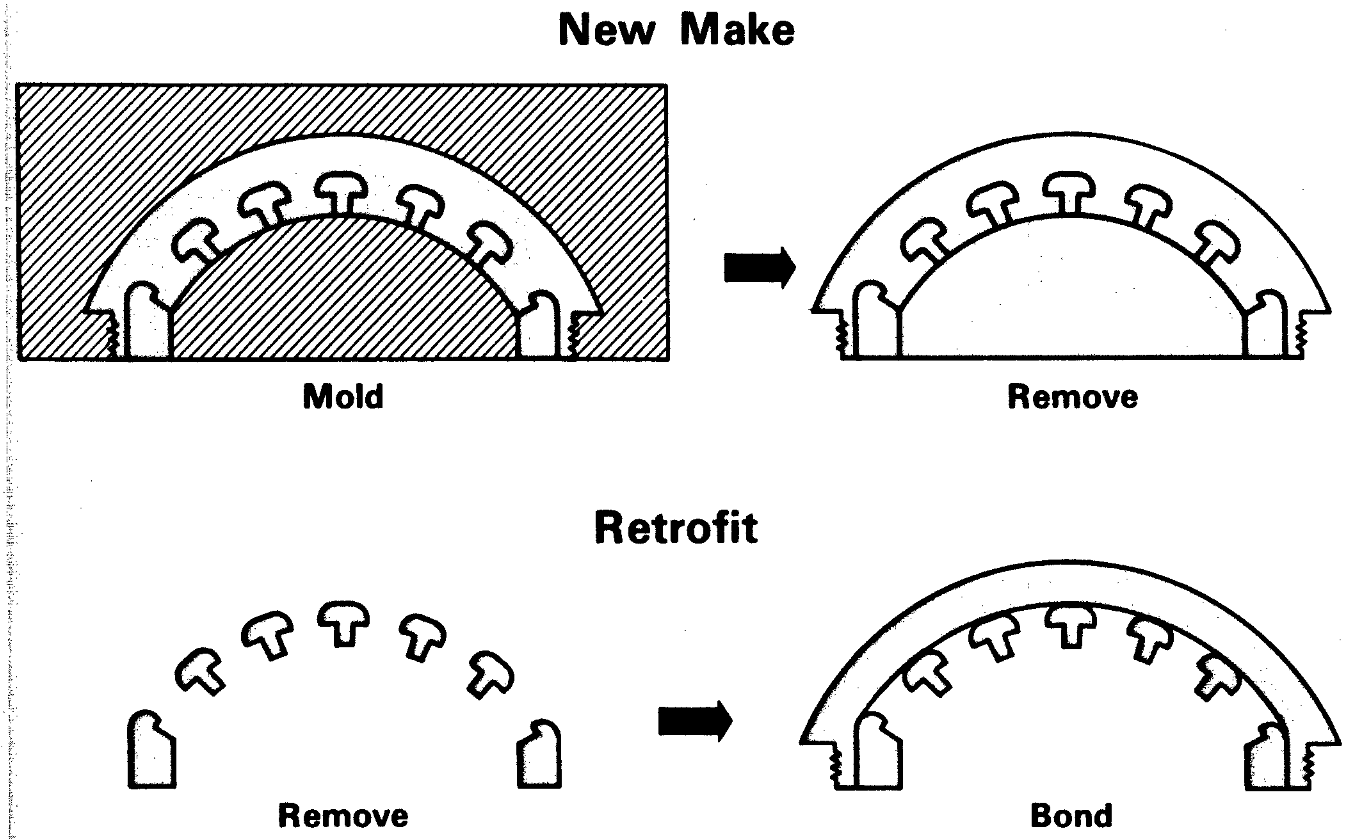


Figure 20

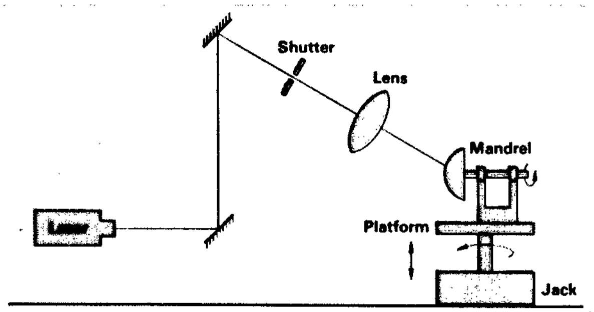


Figure 21

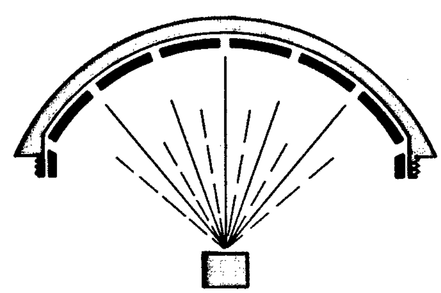


Figure 22

Conclusion

Demonstrated was a manufacturing process for placing fine metallic grids on the curved surface of the plastic nosecone. The process is based on a low-cost flexible circuit board fabrication technique. The metallic mesh process may be used either for new nosecone fabrication or for retrofit of existing nosecones. Three retrofit nosecones were delivered for evaluation.

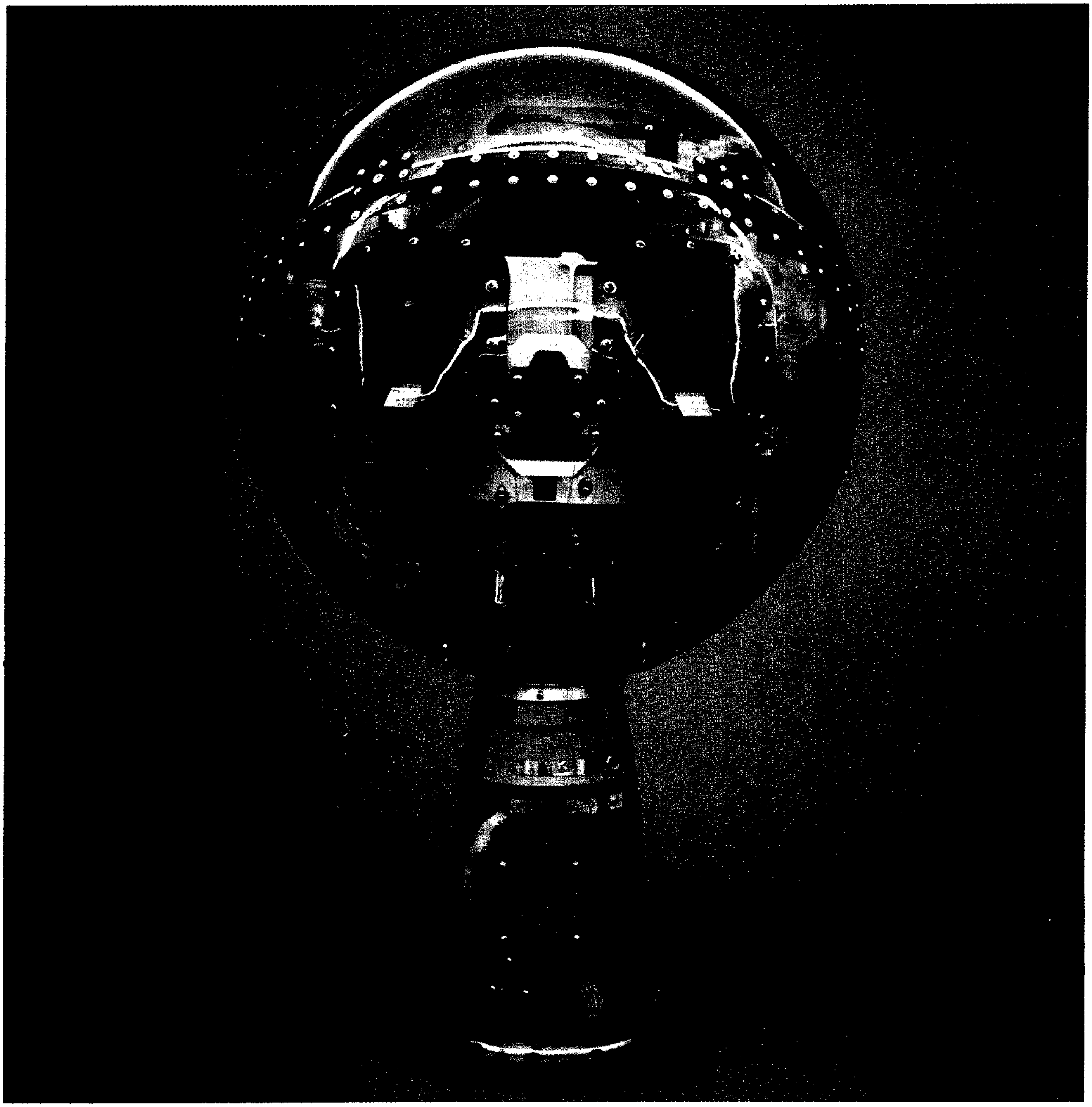
An alternative process was briefly considered, also. This involves vapor deposition of the grid directly onto the plastic nosecone. An evaporation mask was fabricated using the retrofit process described above. The mask is similar to the negative of a grid.

The advantage of the metallic grids are several: rugged, simple construction and effective; the process looks very economical and very promising.

US Army
ManTech Journal

Earlier MT Consideration

Volume 9/Number 4/1984



USArmy

ManTechJournal

Volume 9/Number 4/1984

Contents

About the Cover:

Model of a prototype of the U.S. Army Aviation Systems Command mass mounted sight (MMS) system used on the AHIP-OH-58D helicopter is shown on the cover of this issue of the U.S. Army ManTech Journal. The sensor support structure (S^3) of the MMS, which currently is made of beryllium, is the object of an AVSCOM mantech task in which advanced composites are being used to make the S^3 more producible and less costly to manufacture. This task will be the subject of a future journal article.

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Comments by the Editor

The year 1985 will witness continuing change in manufacturing technology developments, both within the services and in industry. The recently completed 16th Annual Conference of the Department of Defense Manufacturing Technology Advisory Group (MTAG) presented several perspectives on these impending changes, featuring special presentations on the factory of today, the factory of tomorrow, and the DoD industrial modernization incentives program. These outlined some of the changes modern production practices are undergoing—changes that are being addressed by several different organizations, both government and private.


RAYMOND L. FARROW

A recent newspaper account by United Press International briefly summarized a new report on the factory of tomorrow that was the result of a National Science Foundation funded study by the Purdue University Industrial Engineering Department; we have contacted one of the principal authors, and plan to carry an article on the findings of the study in the next issue of the ManTech Journal. We think our readers will find the projections presented in this report of extreme interest.

A significant aspect of these findings is the predicted effect of future manufacturing procedures on the white collar work force. This projection would indicate that the Army certainly is on the right track with its current thrust to extend the capabilities of its manufacturing engineers through an active program of continuing additional training. Greater demands on the individual talents of engineers in manufacturing will be the norm as we proceed toward the next century.

The Army program was the main topic in the last Army ManTech Journal of an editorial by Frederick Michel, Deputy Chief of Staff for the U.S. Army Manufacturing Technology Program at the Army Materiel Command Headquarters. As stated therein, the tremendous expanse of the Army production base presents an enormous challenge for Army production managers, who are faced with the demand for modernizing facilities while simultaneously initiating cost efficiencies.

This issue of the U.S. Army ManTech Journal contains a wide range of manufacturing technology articles from several DARCOM commands; also a large number of brief reports on the status of ongoing Army mantech projects. These latter briefs complete the most comprehensive coverage our publication has given in one year of current projects—a practice that we plan to continue into 1985 and beyond as new projects come on stream to replace those being completed each year.

The Tank-Automotive R&D Command furnished us with four interesting articles from their own newspaper, The T-A News, which were prepared by one of their writer-editors for public relations uses. We think our readers will find these short reports interesting and informative. They include discourses on flexible manufacturing systems, chemical agent resistant paints, laser welding systems, and simulated vehicle testing.

The article on replacement of aluminum extrusions in helicopter flooring by composite materials points up the limited application of a newly developed technology due to production factors. The new technique is cost effective in one application while it is not so in an application that involves further complexities of fabrication.

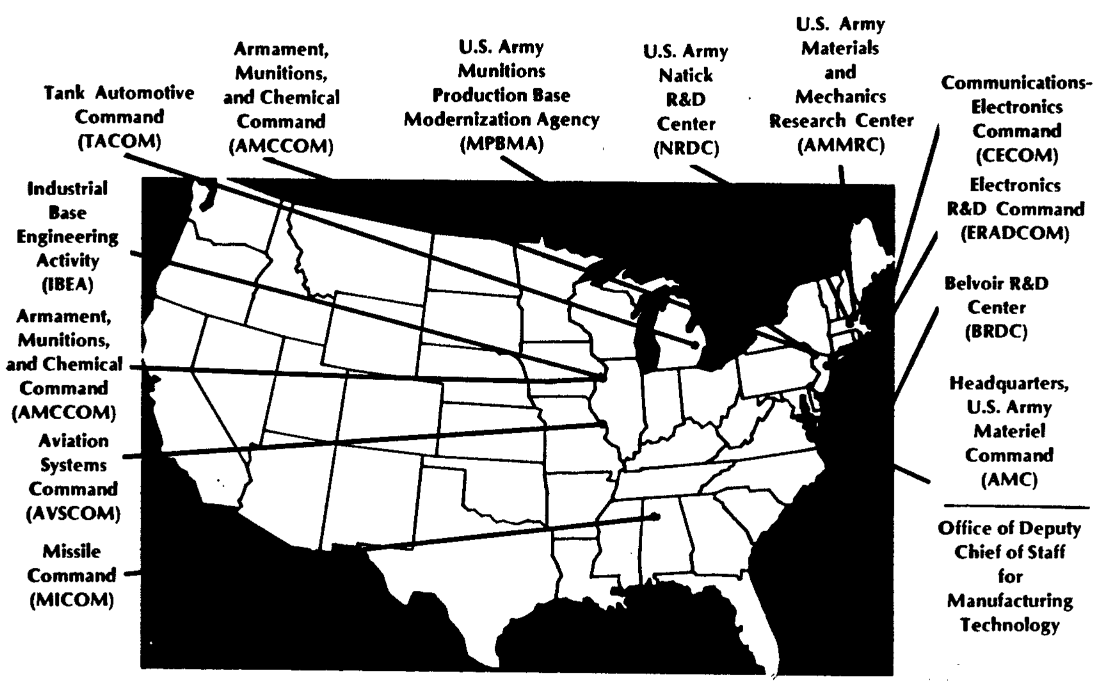
A mantech project funded by the Electronics R&D Command has made possible the production of larger boules of Nd:YAG material at lower cost, as outlined in the article on page 11. This achievement can be expected to have a profound effect on military applications of these lasers in the future.

Another ERADCOM project that will impact future military applications of electro-optics is described in the article on epitaxial growth of gallium arsenide phosphides. This project reflects the foresight of the Army's Night Vision & Electro-Optics Laboratory in anticipating a potential problem of supply for common module arrays used in forward looking infrared devices. The cessation of production by the commercial supplier necessitated the development of a capability by the government to supply its own materials meeting modern performance requirements.

The article on semi-additive printed wiring was based on a paper presented by U.S. Army Missile Command engineer Robert Brown in conjunction with General Dynamics engineer Robert Haner at the 16th National Technical Conference of SAMPE in October of this year. The paper presents an outstanding discussion of the technicalities of this type of fabrication and, through its comprehensiveness, should provide some very useful information to our readers.

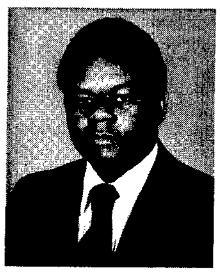
The article on thin film transistor displays on page 42 provides new directions for further development of this promising technology, which is not entirely practical at the present time due to inherent surface morphology problems but which promises to have wide application in the future.

AMC Manufacturing Methods and Technology Community



A Cost Tradeoff?

Composites for Aluminum Extrusions



FREDRICK H. REED is a group leader in the Production Technology Branch, Development and Engineering Directorate, U.S. Army Aviation Research and Development Command, with responsibilities for Producibility Engineering and Planning (PEP), Military Adaptation of Commercial Items (MACI), and Manufacturing Technology. He is a graduate in Electrical Engineering of Howard University, Washington, D.C. (1969) and the DARCOM Intern Training Center in Industrial/Production Design Engineering (1971). Since joining the federal service, he has held various positions in the Army Aviation Production Base Support Program, including AVSCOM Facilities Coordinator and NC CAD/CAM Coordinator for AVRADCOM. Mr. Reed is a member of the Institute of Electrical and Electronic Engineers and the American Helicopter Society.

Complex solid laminate tee section pultrusions when used as chord or cap members in adhesively bonded beam assemblies have been proven cost effective, compared to the installed cost of standard aluminum extrusions. However, pultruded honeycomb sandwich panels are not cost effective when compared to hand layups and autoclave or press cured panels, where extensive operations are required to convert the pultruded sandwich assemblies into more complex beam shear web components.

These were the findings of an MM&T project on the use of pultrusions in the manufacture of medium-lift helicopter flooring, which was done for the U.S. Army Aviation Systems Command by Boeing Vertol.

The Boeing Vertol Company had developed an all composite cargo floor and underfloor support beams for its commercial helicopters. These components were fabricated by conventional hand layup and autoclave cure techniques.

The intent of this program was to combine these two technologies and apply them to the design, construction, and field evaluation of composite flooring and underfloor structure in the new U.S. Army CH-47D Chinook helicopter (Figure 1).

The program was divided into three phases with funds available for Phases I and II only. Authorization to proceed with Phase II was predicated on the results obtained in Phase I. A further goal of the program was to retrofit the floor components developed into an Army helicopter for field service evaluation. Since the main cargo area floor beams are an integral part of the CH-47 fuselage structure, replacement of the metal floor beams is a complex operation. Accordingly, it was decided to select a main beam in the CH-47 cargo ramp shown in Figure 1. The entire ramp structure is easily removed from the helicopter, and new units are in production, thus the composite components can easily be installed during fabrication and the assembled ramp installed on a service aircraft. Accordingly, a main cargo ramp beam subjected to high floor loads and emergency water landing loads was selected for the test item. The beam had a straight aluminum extruded upper tee cap and a stretch formed alumi-

NOTE: This manufacturing technology project that was conducted by Boeing Vertol was funded by the U.S. Army Aviation Systems Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The AVSCOM Point of Contact for more information is Fred Reed, (314) 263-3079.

Figure 1

num lower tee cap containing a moderate fuselage contour which was considered to be post formable when fabricated from a less than fully cured composite pultrusion.

Since the beam was to be retrofitted into a production ramp, all end fittings, fastener locations, cable pass-through openings, etc., had to be compatible with the existing metal structure attached to the beam. This requirement introduced a number of design complexities, many of which could be eliminated in an all composite cargo ramp redesign. The demonstration ramp configuration beam is shown in Figure 2 and the conceptual floor panel retrofit in Figure 3.

Cargo Floor Beam Design

A preliminary design of the composite beam was made, incorporating the necessary existing metal fittings, cutouts and high density compression resistant fastener areas required for retrofit into a production ramp. In addition, the beam was configured to accommodate the higher water landing loads expected in the CH-47D. These loads may result from the higher gross weight and rate of descent specified for the D model.

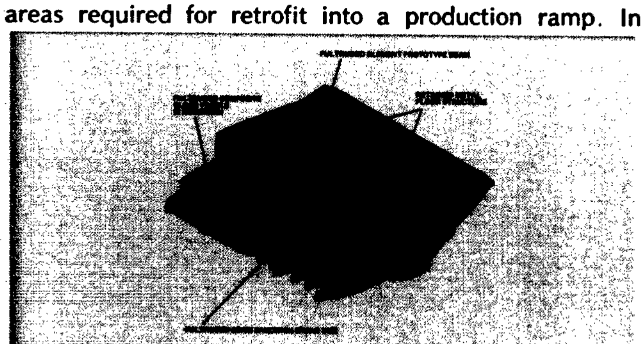


Figure 2

Graphite and Kevlar materials, qualified to Boeing material specifications and compatible with the existing operational pultrusion equipment, were selected. The beam structural design criteria included frame bending and shear design loads induced by water landing and vehicle wheel loads on the ramp treadways. Local design loads caused by the water landing condition were also defined. Those loads are described in Figure 4.

After the basic beam configuration, airframe loads and materials design properties were defined, the main beam components, upper cap, lower cap, and shear web were configured and basic materials and assembly processes stipulated. The design details are shown in Figures 5 through 8.

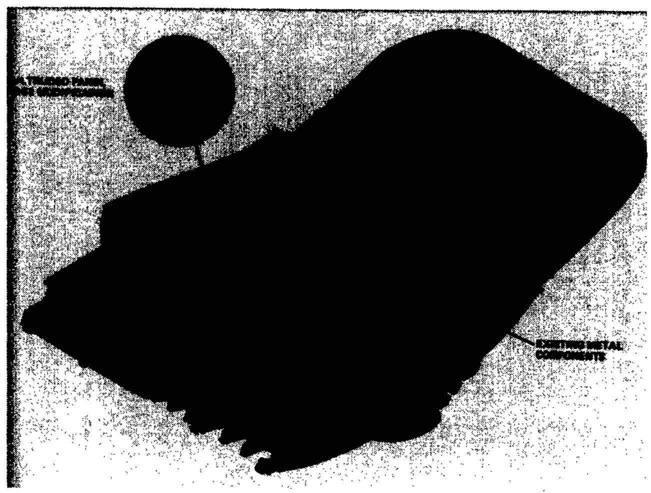
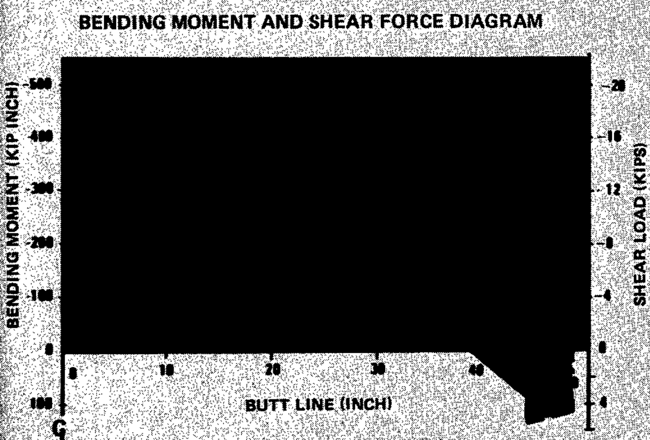


Figure 3

The lower beam cap, due to its twisted and curved contour required to match the fuselage skin contour, was originally designed for hand layup and autoclave cure (shown in Figure 9). However, later work by the pultrusion development group had shown that post-forming was possible in the final assembly beam bond cure process. As a result, in order to make greater use of pultrusions, beam cap pultrusion dies were redesigned to accommodate the larger lower cap dimensions. The smaller upper cap would then be machined out of the common pultrusion cap produced. A structural analysis of the beam was conducted in order to access margin of safety in the composite beam design.

- Frame bending and shear design loads induced by water landing.

  Sink Speed = 8 fps
  Forward Velocity = Zero
  Helicopter Nose-Up Attitude (18^{o}) Locates Center of Water Pressure Under Ramp Frame Station 37.526

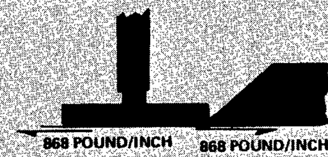


Negative bending moment induces compressive end load in lower cap of frame. Moment about frame neutral axis.

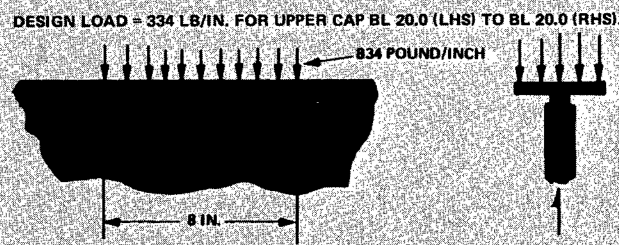
- Frame bending and shear caused by vehicle wheel load on treadway of ramp induces a positive bending moment at ℄ of 123,800 pound/inch. Maximum Shear = 7,500 pounds.

- Local Design Loads

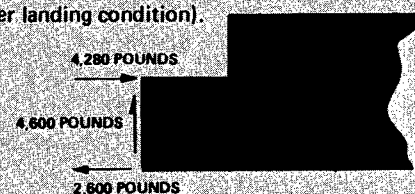
  Lower cap flange must transmit tensile diaphragm skin load of 868 pound/inch (ultimate). Induced by water landing condition.



- Upper cap must be supported in the vertical plane against a vehicle wheel induced load of 834 pound/inch (ultimate).



- Frame end attachments are subjected to the following loads (water landing condition).



- No specific stiffness criteria is required.

Figure 4

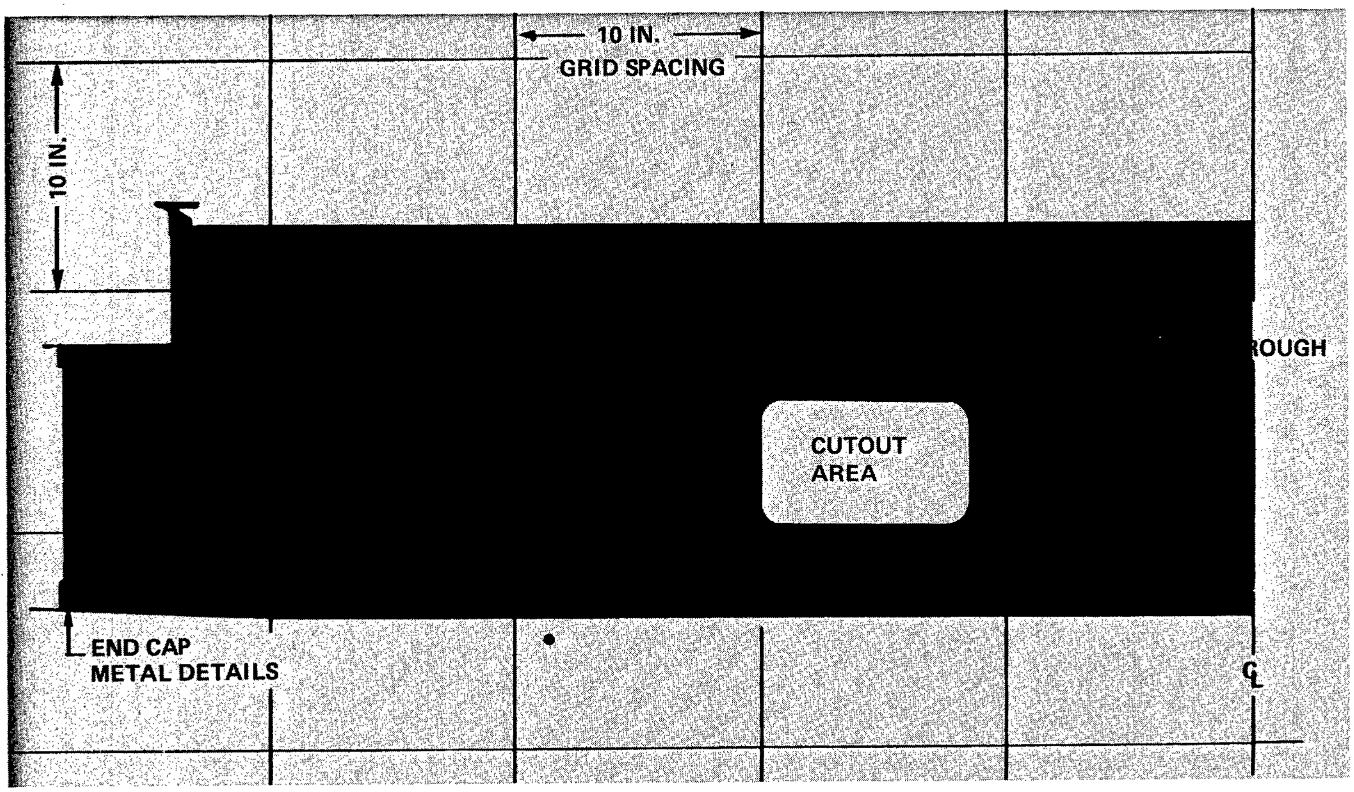


Figure 5

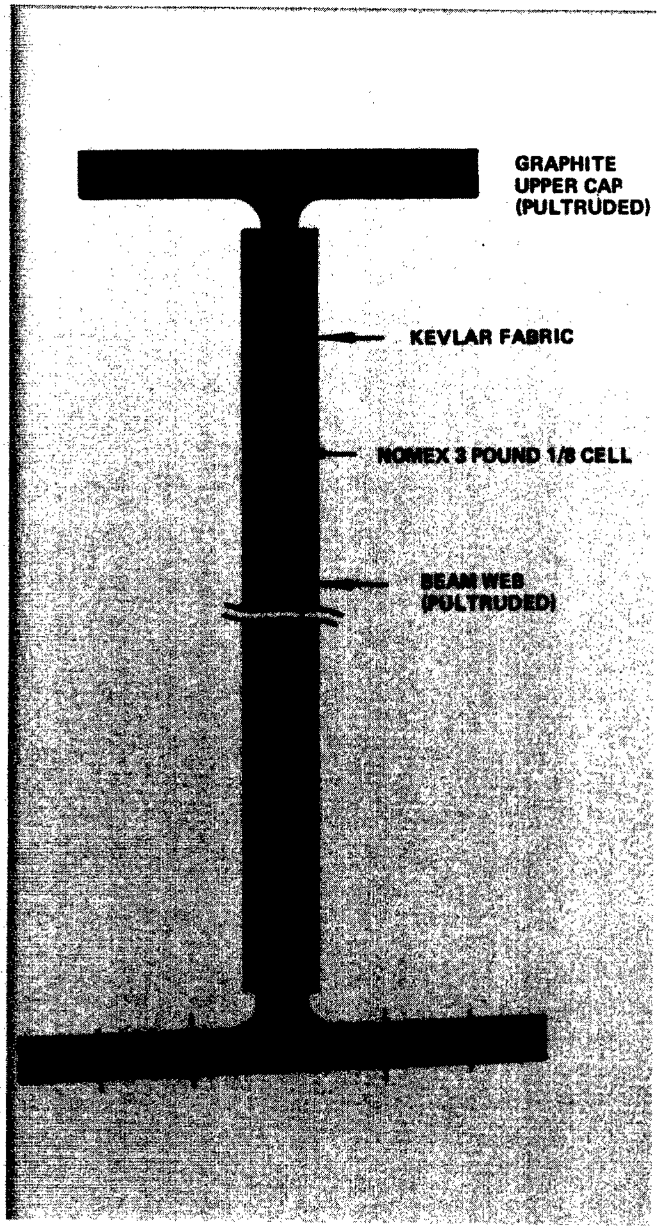


Figure 6

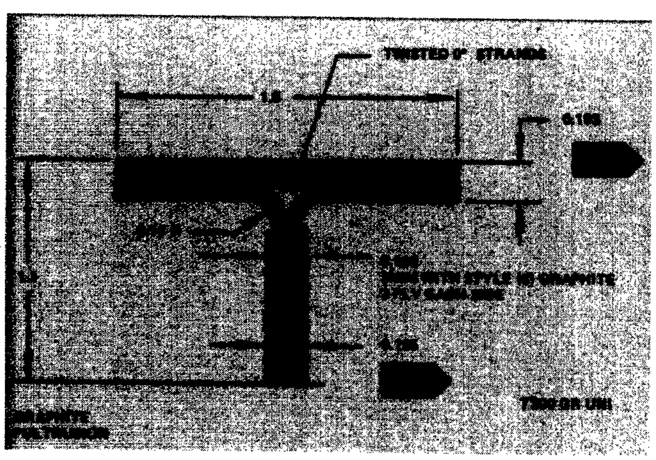


Figure 7

Fabrication Techniques

The program definition required the use of pultruded beam components and floor components, with significant emphasis on the design and utilization of the newly developed sandwich panel pultrusion process.

Since the completed underfloor beam had to be geometrically and functionally interchangeable with the existing metal underfloor beam, a fabrication plan was developed which made use of the existing beam final assembly bonding tools. The pultrusion fabricated beam tee caps and shear web panels were to be cut to final dimensions prior to assembly. The shear web doublers, local hole reinforcements, etc. were to be precut. The honeycomb core around the shear web periphery was to be slotted to accept the cap vertical legs and the metal end fittings. All details were to be coated with film adhesive and the entire assembly adhesively bonded in the production beam assembly tooling.

In preparation for production of the beam components, samples of the tee caps and pultruded sandwich panels previously fabricated were evaluated. Significant details

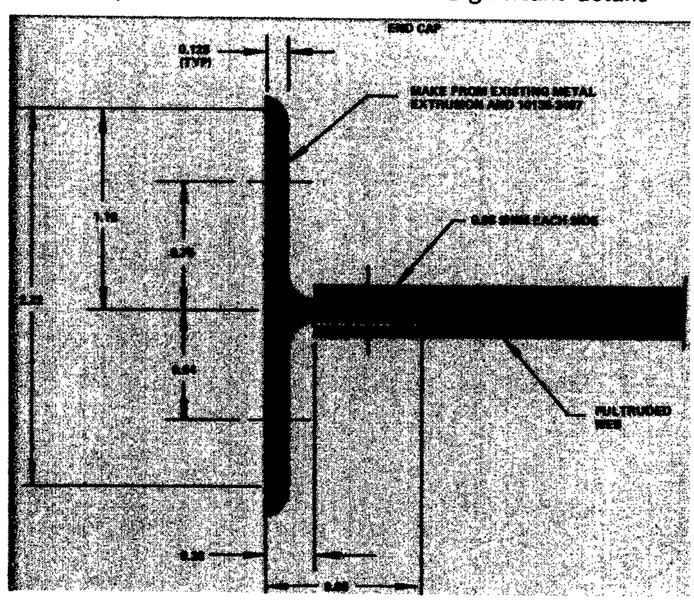


Figure 8

of the equipment, tooling, and component evaluations related to the pultrusion fabrication operations are described in subsequent sections.

Pultruded Beam Tee Caps

Tee cap or beam chord elements were formed and cured with this equipment; they were found to have structural

properties meeting or exceeding those developed by sections fabricated by layup and autoclave cure techniques.

Later work demonstrated that partially cured sections could be bent and postformed during a subsequent cure operation, and it was this concept that was selected for fabrication of the CH-47 lower beam cap element.

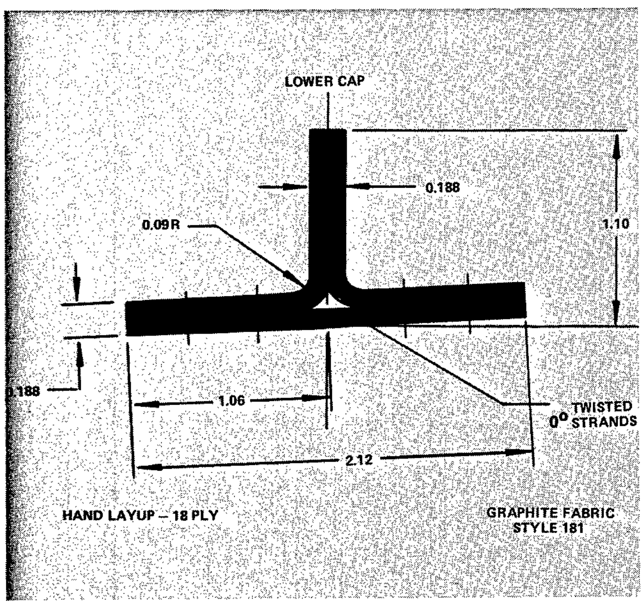


Figure 9

Pultruded Beam Shear Web

The machine developed by Boeing was used to produce 60-inch wide glass fabric faced nomex honeycomb construction. At the beginning of this contract effort, the machine had demonstrated that panels could be made in a continuous process and cut to desired length by means of a flying cut off mechanism. The development analysis had reached the following conclusions:

- Sandwich panels suitable for use in airframe structure can be made in continuous lengths by pultrusion.

- Nomex core must be dried immediately before application of the uncured composite skins when making sandwich panels by pultrusion to assure maximum properties.

- Skins formed of linear fibers cross-plied into a prepreg tape provide a means of self-adhesion to the core by use of a high resin content on the ply next to the core and a lower resin content in the structural face plies.

- Current specifications for sandwich panels can be met by using the pultrusion process.

- Panel thickness varies with the thickness of the core as well as the spacing and pressure on the platens of the pultrusion machine.

One of the principle parameters used in the evaluation of honeycomb panel structural integrity is a skin peel test. A simple skin peel (climbing drum test) test fixture was designed using a torque wrench to quickly evaluate the peel strength of the pultruded panels.

Resin gel time, flow, volatile content, and weight percentage in the prepreg material used for the skin plies could be varied within considerable limits with little effect on panel peel strength when a film adhesive was used as the bond medium. Typical prepreg variations were encountered in the development of panels having adequate structural properties. The Kevlar and graphite prepreg selected for the beam shear web panels to be used in this program was to be evaluated in the same manner in order to set the pultrusion machine process parameters.

Factors Precluding Completion

The program was not completed due to the following factors:

(1) The proposed honeycomb sandwich floor design for the CH-47D was changed to an extruded aluminum stiffened plate due to requirements for maximum cargo area volume, which would have been reduced due to the increased thickness of a sandwich panel floor.

(2) Economic analysis of the continuous sandwich panel pultruder operations, combined with the qualification of additional commercial firms to produce sandwich panels, resulted in negligible cost savings achievable by the continued development and in-house operation of the equipment, and the in-house operation of the sandwich pultruder was discontinued.

(3) After the above decision was made, several commercial pultrusion firms were contacted in an effort to demonstrate sandwich pultrusion techniques on panels of sufficient width to fabricate the underfloor

beam webs. The cost of the large quantity of material, approximately 300 lineal feet, and the requirement to vertically stitch the plies together to insure suitable fiber alignment and location exceeded the program materials budget.

(4) The additional operations required to convert a sandwich panel blank to a more complex underfloor composite beam shear web (cutouts, doublers, stabilized core areas, etc.) forced the assembly back into the detail layup shop and the autoclaves. The resulting costs rendered the approach impractical for the particular design selected for this program.

Economic Analysis

Although the composite underfloor beams were not constructed in this program, sufficient pultrusion equipment operation was performed and related cost data developed to form the basis for a comparative cost estimate between an all aluminum beam and an all composite pultruded shear web and cap replacement beam assembly.

The developed pultrusion cost data, current procurement costs for aluminum extrusions, honeycomb core and sheet aluminum skins, and nomex core, graphite and Kevlar prepreg materials were used in the economic analysis. In addition, the industrial engineering time standards developed for the fabrication and assembly of the metal beam caps and sandwich shear web were used to develop the costs of the metal beam components which were to be replaced with pultruded composite beam elements. Those items which were common to both beam designs—end fittings, fasteners, angles, clips, and brackets—were not included in the cost comparison. In addition, the costs for an all composite beam fabricated by hand layup techniques were estimated.

No manufacturing cost or structural weight advantage was found for the pultruded beam. The completed beam caps manufactured from pultruded graphite stock were actually lower in final cost than the same components fabricated from standard aluminum extrusions. However, the costs associated with the conversion of a simple pultruded sandwich panel into the more complex beam shear web configuration more than offset the savings attainable in the pultruded tee caps. It should be noted, however, that the composite beam was designed for more severe water landing impact than that required of the metal beam.

Table 1 shows the comparison in final assembly/adhesive bond costs for the metal and composite beam elements.

Detail Operation	Metal Conventional	Composite Automated	Composite Hand Layup
Clean and chem process metal details	312	-	-
Clean and process tool BAJ	30	30	30
Apply adhesive to detail parts	270	170	200
NC trim composite panel	-	148.8	-
Fixture route panel edges	-	195.0	
Install potting compound	20	192.0	120
Cut doubler patterns	60	126.0	90
Install doublers	30	30	30
Install details and lower skin	30	-	30
Assemble core details and install	15	-	15
Install caps and end fittings	150	150	150
Close tool	27	27	27
Vacuum bag	60	60	60
Autoclave cure	98.8	98.8	98.8
Paint and stencil PN	45	45	45
Wrap and store	12	12	12
	$\frac{1,159.8}{60}$ = 19.33 Hours	$\frac{1,284.6}{60}$ = 21.41 Hours	$\frac{907.8}{60}$ = 15.13 Hours

Table 1

The Emphasis is on Flexibility

Automated Manufacture for Low Volume Production

By George Taylor
U.S. Army Tank—Automotive Command

TACOM and Draper Labs Inc. have developed computer-aided design procedures that make practical the automated manufacture of low-volume-production items such as military vehicles and components.

The effort is part of DOD's Manufacturing Methods and Technology (MM&T) program to improve military equipment and reduce production cost by using advanced technology.

With the rapid growth in automation technology, the automobile industry and other high-volume manufacturers have come to rely increasingly on automation for machining and assembling parts and performing other routine tasks.

The results of this trend have been reduced labor costs and, in many instances, improved product quality.

Until recently, however, automation has been limited to high-volume production because it was not economically practical to buy expensive automated equipment that could only make large quantities of one specific item.

But advances in the state-of-the-art of automated manufacturing technology now permit the development of flexible manufacturing systems.

Suitable for Small Batches

These consist of arrangements of computer-controlled machine tools and material-handling equipment capable of producing small quantities of a number of similar parts, rather than a large quantity of one part.

According to David Pyrce, TACOM R&D Center MM&T project engineer, this flexibility has great potential in military vehicle manufacturing, where the production volume for a given vehicle may be several hundred to several thousand units. This is too small a quantity for traditional "Detroit Style" automation.

"If you look at what goes into a vehicle," Pyrce noted, "you can find parts which, though not identical, are similar. In a tank, for example, the housings for the various fire-control systems are similar aluminum castings.

"By designing automated machines capable of making enough similar parts, we can get sufficient production volume to make automation feasible."

Complex Automated Equipment

Flexible manufacturing systems are far more complex than conventional automated equipment and would be extremely costly to develop by standard methods. Pyrce said, however, that the computer-aided design approach makes it possible to create and optimize system designs at sharply reduced cost.

In computer-aided design, an engineer creates and modifies design models by entering graphic or mathematical information into a computer. Once created, the model is permanently stored in a data base within the computer and is used in various design and analysis operations.

"The big cost advantage to computer-aided design," said Pyrce, "is that you can literally design a system on a computer and run it to see if it will work, without having to buy expensive machine tools."

TACOM's involvement in computer-aided designing of flexible manufacturing systems began in 1979, when the command awarded Draper, a pioneer in flexible manufacturing technology, the first of five contracts for a two-phase, five-year effort.

In the first phase, Draper developed a family of computer programs that simulate flexible manufacturing and a methodological approach for using the programs to design a system. This effort included the publication of a five-volume methodology handbook for manufacturers.

NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

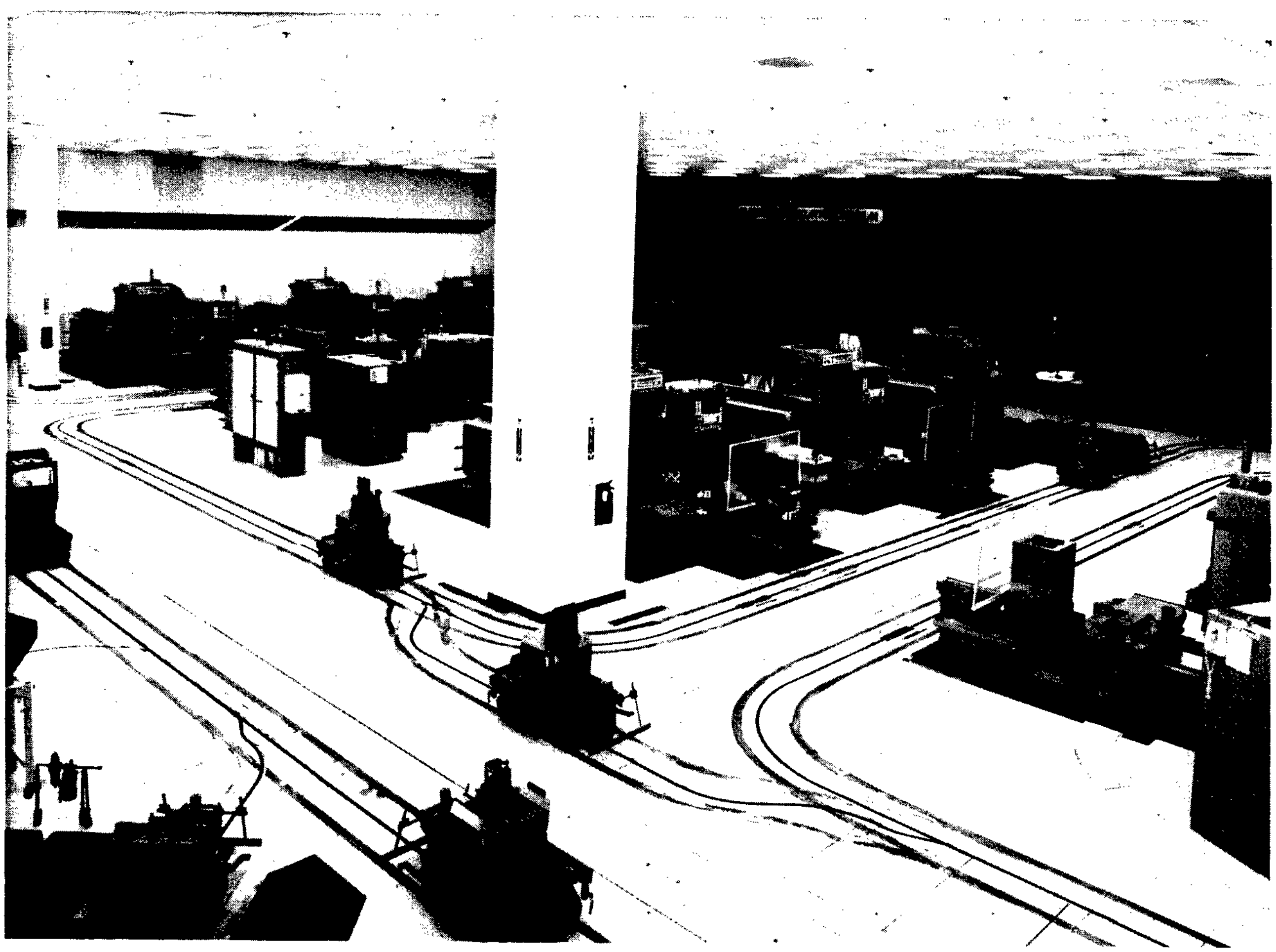
In the second phase, Draper assisted four major Army suppliers in using the programs to design flexible manufacturing systems for production facilities—three of which have decided to buy equipment.

Two Systems Operational

To date, two complete systems have been designed and installed. One of these is at an FMC plant in South Carolina that is soon to begin production of Bradley vehicle suspension components.

The other is located at a Hughes Aircraft plant in California that makes M1-series tank fire-control system housings. Also, work is underway to develop a flexible manufacturing system for use at Rock Island Arsenal, a major supplier of gun components.

Pyrce said that once a system has been designed, the computer programs can serve other purposes, such as scheduling, process planning, determining batch quantities for the parts being manufactured, and mapping contingency plans in the event that a machine tool should fail.



HUGHES AIRCRAFT'S FLEXIBLE MANUFACTURING SYSTEM FOR PRODUCTION OF M1 FIRE CONTROL SYSTEM HOUSINGS. IN OPERATION, THE AUTOMATED CARTS TRANSPORT EACH PART AND ITS FIXTURE FROM ONE MACHINE TOOL CELL TO ANOTHER.

New Growth Process Increases Size

Larger Laser Rods Produced

by

Albert Pinto
U. S. Army Night Vision and Electro-Optics Laboratory

Large single crystals of neodymium doped yttrium aluminum garnet (Nd:YAG) required for future military program applications of optically pumped solid state lasers are now possible. From its discovery in 1964 until the present time, the most expedient method of obtaining such crystals of laser quality has been by means of the Czochralski growth procedure. In current production practice, this method consists of seeding and pulling a crystal from a melt contained in an iridium crucible. The crucible is heated by means of kHz radio frequency induced currents. While the process is a good one it has remained virtually unchanged except for improvements in diameter control systems.

Under a U.S. Army Electronics R&D Command program, the Airtron Division of Litton Industries, Inc. developed a production process which yielded boules of 30-38 mm diameter. For nearly ten years this process has remained the same and few workers attempted any improvement. In the period 1976-77 an increased demand for laser rods engendered an examination of procedures to increase yields. A concurrent objective was the lowering or stabilization of growth costs during a period of high inflation. The principal contributions toward the cost of a laser rod are iridium, electrical power, materials, and labor. Thus, any process which limits or eliminates any of these would be beneficial. During the natural evolution of material growth technology, the trend has been to grow larger crystals. A valid question often has been asked: why not grow larger boules of Nd:YAG?

Three Methods Possible

The justification for larger boules of Nd:YAG is based on the need for greater yields of high quality material at lower costs. This can be accomplished theoretically by the following approaches:

(1) Grow crystals at current production diameters and maintain quality.

NOTE: This manufacturing technology project that was conducted by Airtron Division of Litton Industries for the U.S. Army Night Vision and Electro-Optics Laboratories, was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The ERADCOM Point of Contact for more information is Bob Moore, (202) 394-3812.

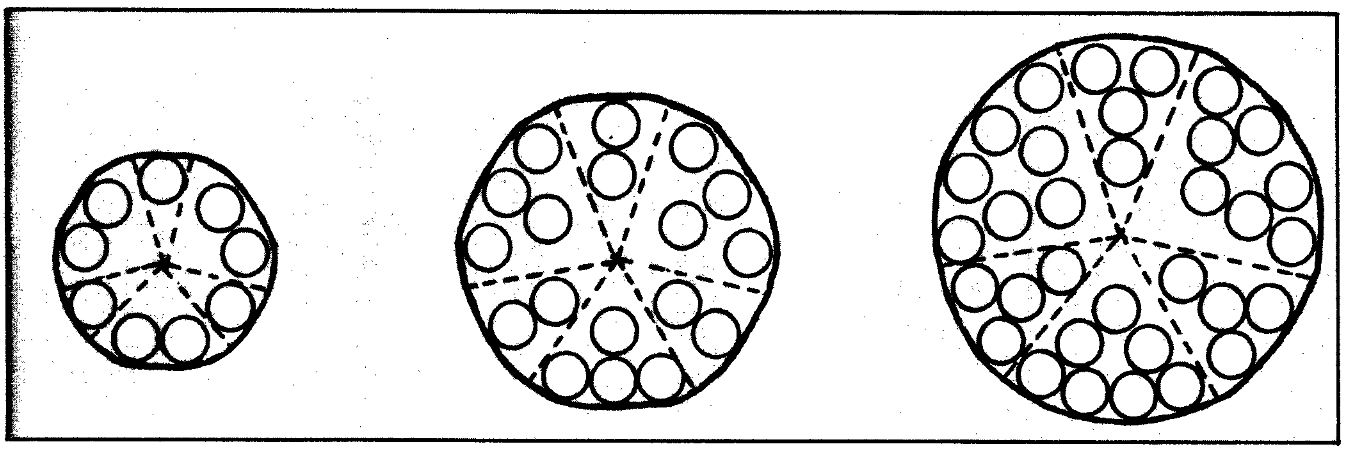
(2) Grow larger diameter cyrstals at the same length and quality.

(3) Improve the optical quality of boules by maintaining the melt composition fixed. This could occur in combination with any advance made in (1) and/or (2).

If the first course is chosen, the growth rate still remains fixed and not much is gained. This is complicated further by the Nd level in the crystal which constantly increases and eventually causes high strain or exceeds the laser rod concentration specification. If the third course is followed, a substantial improvement results, but the time frame for realizing such an effort is certainly several years. Thus, the most promising alternative is the second approach—to grow larger diameter crystals. An increase in diameter to about 50 mm would almost double the rod yield from a boule and seems to be within capabilities based on recent experiments.

Nd:YAG Growth Complicated

Early experiments were begun at Airtron in 1976, and by 1978 a few 50 mm boules were grown with moderate success. These results led to an initiation of the present program to refine the technique for production purposes. The increase of boule diameter of any Czochralski grown crystal is a formidable task. Good methods have been developed for silicon, GGG, and sapphire over a period of years. The degree of difficulty is associated closely with the operating temperatures, number of chemical components, and factors which govern melt behavior. Nd:YAG growth is complicated by a melting point of 1975 C, a three component system, low distribution coefficient (0.18) for Nd, faceting phenomena, and high melt thermal convection. In addition, the growth rate of Nd:YAG from the melt is a rather low 0.5 mm/hr. This places an extremely high demand on the temperature control system. Fluctuations of 10-20 C cannot be tolerated during the entire growth cycle of 2-3 weeks. At the present time, there is no known method to increase growth rate without some sacrifice in quality. Hence, for any planned increase of boule diameter, all the usual problems are not only present but also aggravated. In spite of inherent difficulties with Nd:YAG, it is safer to follow the Czochralski growth route rather than an entirely different procedure. In order to place the objectives of growth in perspective, it is recalled that a popular size of laser rod required in large quantities is the (4.3 x 43) mm cylindrical type. A boule diameter increase from 35 mm at present to 50 mm will almost double the rod yield from a boule. Figure 1 shows a typical boule diameter at each chronological stage of growth development. It also records the number of laser rods of a (4.3 x 43) mm size that can be extracted from such a diameter. Notice that in Figure 1c an increase of only 5-6 mm in the diameter nearly doubles the rod yield from that of Figure 1b, which is current production. Of course, this increase needs to be done at no sacrifice of quality or growth time.



(a) 1967-1972 27 mm dia **(b) 1972-1978 38 mm dia** **(c) 1979 50 mm dia**

Figure 1

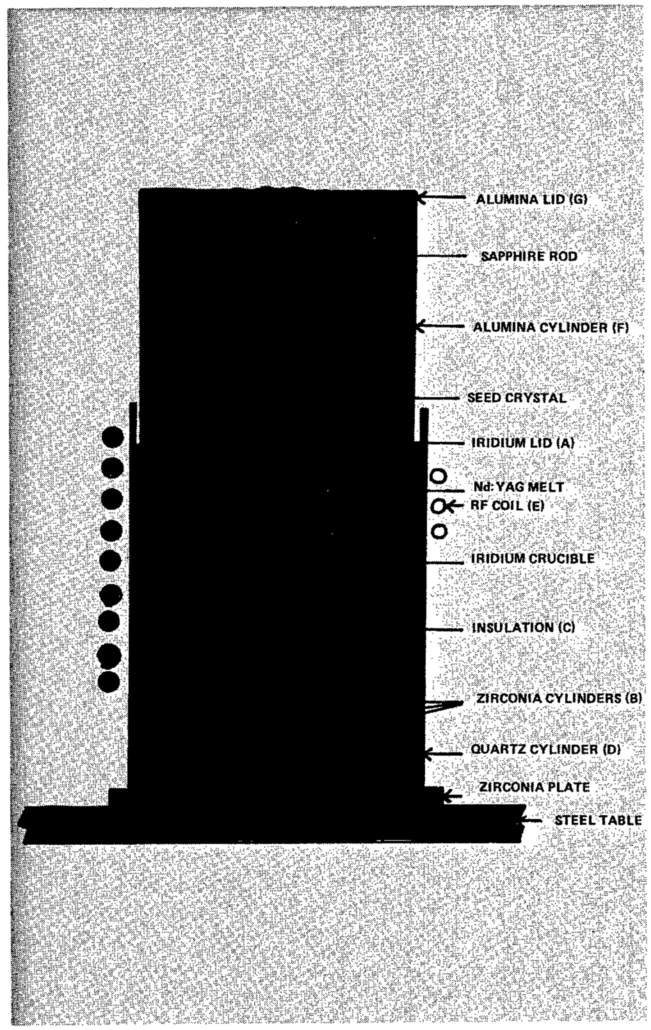


Figure 2

Basic Process Used

The basic approach utilized to achieve good quality growth has been to adjust the crucible position within the coil as a means of varying the radial temperature gradient in the melt. It is not clear what the correct gradient should be with the type of growth station design employed. However, previous growth results indicate that a steeper radial gradient is required based on the severity of crystalline defects which have appeared prior to the crystal reaching final diameter. In all growth experiments the radial temperature gradient has been 25-30 C per centimeter. This is substantially lower than the existing gradient in production growth stations, and it has been a difficult parameter to control.

A conceptual view of the basic crystal growth station is presented in Figure 2. A 4.5-inch-diameter and 4.5-inch-high iridium crucible with cover (A) is supported by concentric zirconia tubes (B). This arrangement is surrounded by zirconia grain insulation (C), which is enclosed by a quartz glass tube (D). Power is applied to the crucible by means of an rf coil constructed from circular copper tubing (E). The area above the crucible into which the crystal is pulled is insulated by means of an alumina tube (F) and an alumina cover (G).

To provide a situation for experimental growth similar to that existing in the production growth of smaller diameter crystals, the crucible size has been optimized at a 4.5 inch diameter and 4.5 inch height. This ensures that for a given length of crystal the neodymium dopant concentration typifies that of production crystals and permits the duplication of crystal growth rate. The charge for a crucible of this size capacity is approximately 4300 grams. The expected weight of the pulled crystal is about 1 kg, so no more than 20-25 percent of the melt is removed.

Oxides used for experimental work are obtained from supplies used in the production growth area. These are readily available from commercial vendors at grades of 5-9's and 6-9's purity. In the case of the yttrium and neodymium oxides the purity refers only to the rare earth oxide assay, however. Thus, care must be exercised to insure that contaminants do not affect the crystal growth or laser performance of fabricated rods.

Careful Procedures Required

The growth furnace is constructed by carefully aligning ceramic elements and the crucible for cylindrical symmetry. The oxides are blended to a homogeneous mixture and are then added to the crucible. In order to initiate growth, the melt temperature is adjusted to maintain the seed diameter when contact is made with the melt surface. If a diameter increase or decrease occurs, the temperature is adjusted upward or downward as required to maintain seed diameter. When pulling commences, the automatic diameter and temperature control systems are initiated and growth continues until the desired crystal length is obtained. The growth is then terminated and the entire furnace is cooled to room temperature over a period of several days.

The initial portion of the growth process consists of cutting all ceramic elements to the proper size prior to arrangement of the growth furnace. These are then dried in an oven to eliminate moisture introduced during the sawing process. This having been done, the growth station is constructed.

All components are centered with respect to the centerline of the pulling mechanism. The zirconia cylinders are placed concentrically within the outer quartz sleeve. Zirconia grog is then packed within all open areas to the top of the zirconia cylinders. This having been accomplished the iridium crucible is wrapped with a layer of zirconia felt, which is secured to the cruicible with sewing

thread. The crucible is then centered atop the zirconia cylinders. The specially prepared insulation is added around the crucible to a position just below the top and the crucible lid is placed atop the crucible. Care should be exercised to insure that no contamination occurs on the crucible's internal surface. The growth station is completed with the addition of the alumina cylinder and lid, which act as an afterheater.

The growth furnace having been arranged, it is surrounded by a Pyrex bell jar, and the system is purged with a mixture of nitrogen with 0.05 percent oxygen. Power is also supplied at a low level to the crucible to eliminate residual moisture within the growth station. While this is being done, the crucible charge is prepared. The individual oxide components are weighed to 0.2 gm and blended for about one hour to insure thorough mixing. This mixture is then placed in clean beakers in preparation for loading of the crucible.

The crucible loading procedure should normally take several hours and is accomplished by gradually feeding the oxides into the crucible through a quartz tube while the power is increased slowly to melt the material. This operation is completed with a temperature at the melt center established below the crystal melting point. A seed holding mechanism is then fed into the growth station in preparation for initiating growth.

Prior to actual growth, a solid crystalline mass is generally present at the top center of the melt. This is dissipated by further adjustment of the power upward. A crystalline seed of the proper orientation is then dipped into the melt and the power is further adjusted to melt any solidified material back to the seed diameter. At that point the pulling operation is commenced.

In order to obtain the highest quality, an automatic diameter control system is utilized. The crystal is smoothly programmed from seed diameter out to its desired diameter and growth is allowed to proceed until a satisfactory length is obtained. At that point, the pull and rotation are stopped and the power is programmed down over several days.

Following extraction of the crystal, the crucible is removed from the growth station, the residual solidified melt is removed, and the crucible is cleaned. The growth station is then rearranged with a clean crucible and the growth process is repeated.

Early Run Examples

The first three growth attempts were designed to evaluate the performance of the control system with a new, larger power supply. A smaller 4-inch-diameter crucible was utilized with a standard growth station design (Figure 3) in order to make a comparison with results of growth runs made prior to initiation of the program. Some problems were experienced with melt contamination which originated from flaking of the quill used for holding the seed rod. This was caused by the higher temperature in the vicinity of the quill. Once the problem was identified, the diameter control system functioned normally, although poor control resulted from the effects of the contamination. For subsequent growth runs the larger 4.5-inch-diameter crucible was put into service.

A second series of growth runs were performed with a watercooled bell jar system. This approach was found to work very well since the excessive heat evolved from the growth furnace was effectively conducted away by the watercooled enclosure. Without this system it would have been impossible to work in the vicinity of the growth furnace; also, the heat would have had a deleterious effect on the electronic control system.

Growth at Seed Diameter

Experience in the production growth of Nd:YAG indicates that the best results are obtained if the crystal is

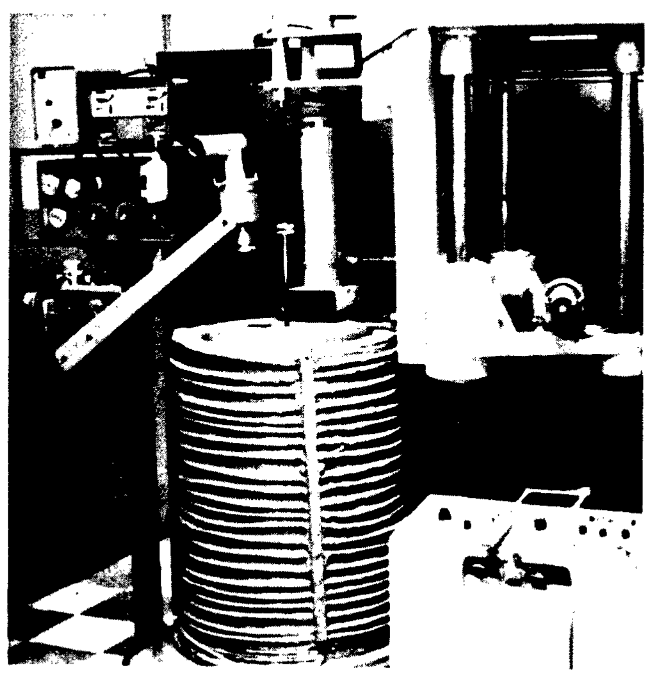


Figure 3

allowed to grow with a very steep solid/liquid interface projecting down into the melt. While this highly convex shape results in a core formation from facets developed at the tip of the growth interface, most of the strain is confined to a 3-4-mm-diameter core region. High quality laser rods can then be extracted from the outer portion of the crystal cross section and in between the radial strain lines.

An unfortunate consequence is that the disturbance of the crystal diameter normally results in a blossom (local high strain) fanning out from the central core. This situation also exists if the growth interface is not convex enough, since the faceted central region then has a tendency to trap liquid or secondary phases which result in defects.

Methods of insuring that the crystal maintains a highly convex profile are either to provide large temperature gradients or to utilize low rotation rates. The latter method alone is not very effective in the growth of Nd:YAG, since the rotation rate has little effect on interface shape except at high rotation rates (100 rpm). Thus, the former method is resorted to for production growth.

For the situation which exists during growth of the larger diameter crystals, care must be exercised because the crucible size and growth station design tend to increase the temperature gradients. Efforts to increase the existing gradients can lead to cracking when the yield strength of the crystal is exceeded.

Most of the initial work during this program favored crystals which contain blossoms arising from a shallow interface shape. In many cases the resulting strain was so gross that extensive cracking of the crystals resulted. Blossom formation occurred at diameters of 0.5-1.0 inch. An alternate method of lengthening the growth interface was attempted, and early results indicate that some improvement in growth occurred. In this instance, initial growth was conducted at somewhat larger than seed diameter for an extended length and the crystal diameter was then increased slowly to its final value (Figure 4). It was felt that the additional heat sink capacity of the extended length of small diameter crystals would provide a steeper growth interface and therefore overcome the blossom formation in the 0.5-1.0-inch-diameter range. Radiative losses could then maintain the steep interface as the crystal diameter was increased. Whether an improvement in growth results from this approach was not clear, since only two growth runs were completed with this technique.

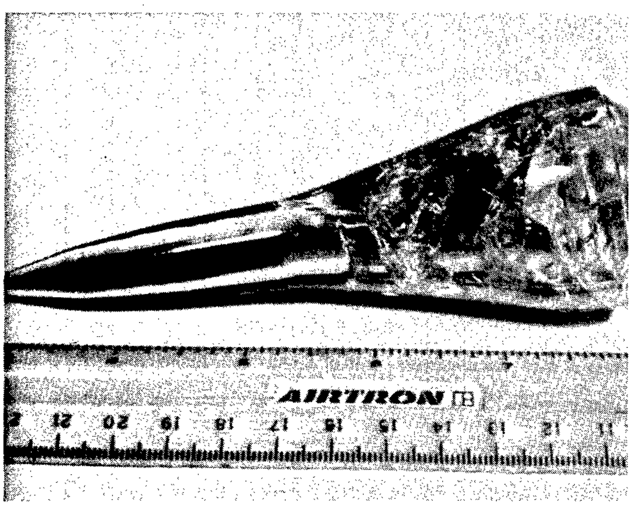


Figure 4

Melt Gradients Most Important Parameter

It is felt that the most important parameter requiring control during the growth of Nd:YAG is the radial melt temperature gradient. Because of the crystal's high melting point (1950 C), it is difficult to measure a gradient directly by accurate methods. One approach which has been utilized satisfactorily is to scan the melt surface with the optical pyrometer used for diameter control. This method has been found to be repeatable and has proved to be useful for qualifying the growth results of various growth station designs.

Figure 5 illustrates the results of two such scans for different growth station designs. Although similar in some respects, these charts have one characteristic which may be related to blossom formation at small crystal diameters. It can be seen that the radial melt temperature gradient is higher at smaller melt radii and then decreases as the distance from the melt center increases. This means that constitutional supercooling can occur at small crystal diameter if the rate of the diameter increase exceeds the ability of the diameter control system to maintain the crystal on its program. Ideally, the radial gradient should have a low slope more typical of that observed at the larger radii in Figure 5.

Problems Analyzed

The major difficulty which has prevented growth of larger diameter crystals of high quality has been the internal blossom generation at small crystal diameter. This has led to an inordinate amount of strain in most cases and

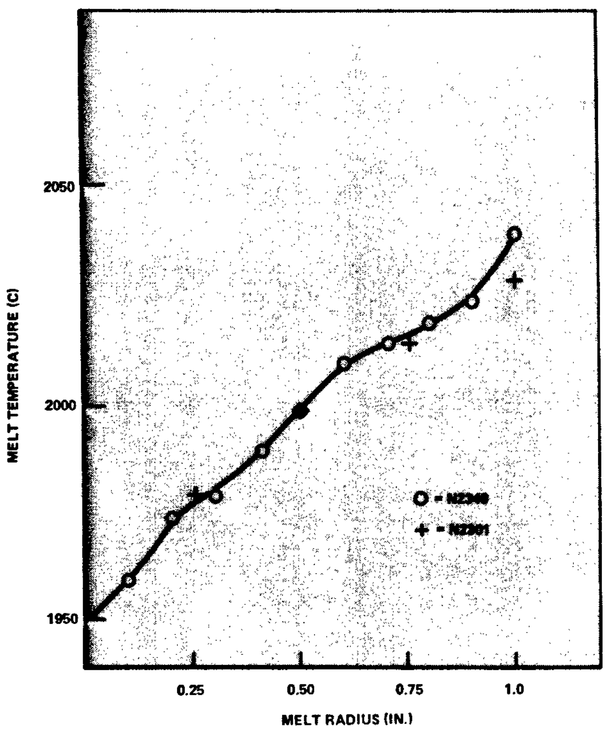


Figure 5

finally the crystal cracks. However, even in the cases where the strain from blossom generation is comparable to that encountered in production growth of smaller diameter crystals, cracking has occurred. It would appear, therefore, that the larger diameter crystals are unable to withstand the greater differential thermal stress between the cold surface and hot center of the crystal. A simple remedy for this appears to be a top heater.

The most recent growth results indicated that defect-free crystals of even larger diameter should be obtainable. While improving the growth station design, attention should be given to the area above the crucible into which the crystal is pulled during growth. Better insulation of this chamber should reduce the thermal loss and thus the differential thermal stress and tendency toward cracking. However, this is expected simultaneously to affect the radial and axial gradients so that blossom generation is prevented and thermal shock is alleviated.

The greatest difficulty in this program, however, has come from defect generation as the crystal approaches final diameter in its growth cycle. Although constitutional supercooling is inherent in the growth of Nd:YAG and slow growth rates must be utilized as a result, the aforementioned problem does not seem to be related mainly to growth rate.

Data on the typical radial melt temperature gradient were obtained with the growth station design. The most significant aspect of these data is that the gradient does not change much with small changes in the growth station design. While it would be desirable to obtain a gradient as near as possible to that existing in production, this leads to some serious problems with the growth stations involved.

One important feature is that a gradient of the required magnitude would push the crucible wall temperature close to the iridium melting point. This would make operation at growth temperature marginal and associated growth operations procedurally difficult. Another feature is that the additional heat loss from the growth station due to a higher radial gradient puts some constraints on the power supply in that the higher power output required raises the output voltage to a point where high voltage discharges tax the power supply's reliability. In spite of these difficulties a unique solution was found to modifying the radial melt temperature gradient. There appears to be a direct association between the institution of this change and the better growth results toward the end of the above experimental work.

Novel Approach

It should be noted that most of the insulating ceramics utilized for crystal growth are composed of zirconia. While this material possesses good thermal insulating properties by virtue of its relatively low thermal conductivity, it is also quite transparent to blackbody radiation at the crystal growth temperature.

Figure 6 represents a curve of the blackbody radiation from an emitter radiating at 2300 K, the approximate melting temperature of Nd:YAG. The peak of this curve lies at about 0.7 millimicrons where zirconia is transparent. Thus much of the infrared energy passes through the normal insulation used in the growth station. A material doped with dysprosium has very strong absorption at this same wavelength. A novel approach was utilized to effectively limit the amount of radiation escaping from the growth station and thus improve the insulating properties.

An alternate type of zirconia insulation was prepared by crystallizing the cubic form of zirconium oxide stabilized with dysprosium oxide rather than yttrium oxide or calcium oxide which are normally used. This material was prepared by growing dysprosium oxide (40 mole percent) stabilized cubic zirconia crystals with a patented growth process and then reducing these crystals to a granular

form compatible with the growth station design. This procedure was initiated with a growth run where the top two inches of insulation surrounding the crucible were replaced with the alternate insulation. A pyrometric probe of the radial melt temperature gradient for this run showed what appeared to be a refinement of the gradient near the center of the melt. While this was a gross measurement the true effect was realized when this crystal growth cycle was brought to completion without the crystal cracking. This was the first time a growth run at the large diameter was brought to completion in such a manner. The three subsequent runs also were completed by replacing all of the insulation surrounding the crucible with this alternate material. The absence of cracking in spite of extensive flaws indicated lower bulk crystal strain using this approach.

The real effect of this design change is not completely understood at this point but it is theorized that instability in the melt convection has been eliminated near the melt top center. Thus the tendency for generation of defects at the crystal core has been reduced. The next problem which has to be dealt with is some further modification of the growth interface to offset the tendency for defect generation due to constitutional supercooling. This has been approached initially by reducing the growth rate. However, this is an undesirable situation for improving the growth efficiency. It is believed at this time that the thermal convection in the absence of crystal growth is quite similar to standard production crystal growth. Further refinement in the growth can be expected, therefore, by evaluating the effects of crystal rotation rates on the growth quality.

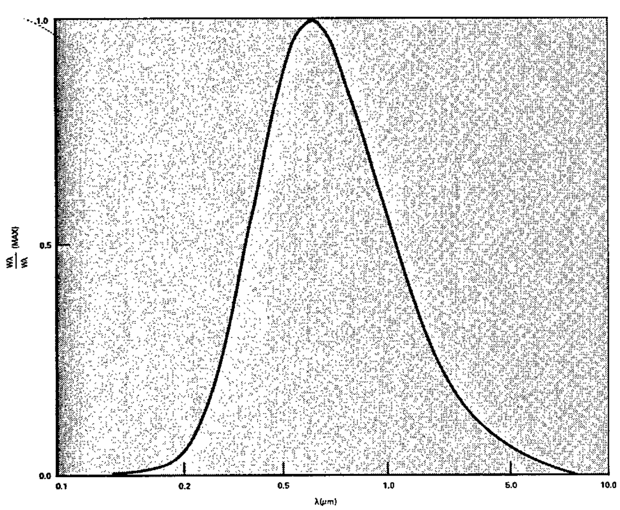


Figure 6

Further Size Increase Possible

It was demonstrated early in this program that large Nd:YAG melts can be handled successfully for growth of 2.0 inch diameter boules by means of the Czochralski method. Ideally the crucible diameter should be about twice the boule diameter. The 50 kW and 450 kHz production radio frequency growth stations can melt easily the charges of 4.3 kg needed for large boules.

To grow good quality crystals, careful control of both longitudinal and radial melt gradients is necessary when a steep interface is present and faceting occurs. The most important of these is the radial gradient and for a large system it can be reduced by a judicious choice of insulation. Zirconia with a stabilizing additive of dysprosium oxide was found to give good results.

With an optimized growth station geometry and a given growth rate of 0.5 mm/hr, the remaining variable is rotation rate. In order to match the melt isotherms closely to the growth interface, values of around 15 rpm or less gave a high quality boule free of precipitates or strain.

A growth process was developed which gave finished boules meeting the suggested goals of 50 mm diameter and 75-100 mm long. Late in the contract, boules were obtained which yielded 40-60 laser rods of a (4.3 x 43) mm size. This was well above the goal of at least 30 rods which completely meet a current AN/GVS-5 specification.

All laser rods were fabricated by a batch process developed for polishing 15 rods in a single fixture. The engineering, confirmatory, and pilot production samples were extracted from production boules and fabricated under an existing rod process. Quality control passive tests of the rods showed that specifications were retained by more than 90 percent of the extracted rods.

It appears that the boule growth results obtained under this program are transferable to current production stations. Since only one station was in operation the entire length of the effort, insufficient growth statistics were generated to forecast high boule yields. Thus some problems of cracking, blossoms, poor starts, equipment failures, and materials choice are still apparent. On the average these are no worse than results obtained with smaller diameter boules.

Results obtained indicate that further increases in boule size are possible. However, the proper RF unit, diameter control, and furnace geometry need to be combined for growth near 3.0 inches.

Manufacturing Capability Established

Epitaxial Growth of GaAsP Material

by

Mrs. Marilyn Jasper
U. S. Army Night Vision & Electro-Optics Laboratory

Continued production of common module arrays for FLIR systems now is assured, following the successful completion of a U.S. Army Electronics R&D Command manufacturing technology project. Conducted by Honeywell Optoelectronics for the Army Night Vision & Electro-Optics Laboratory, the program was initiated in 1977 to provide a government manufacturing capability for arrays. At that time, the major supplier of GaAsP material was preparing to discontinue operation, potentially leaving no viable source. The uncertainty of a continuing supply of suitable high brightness material presented a threat to array production for the government.

The critical component of FLIR modules is the GaAsP light emitting diode (LED) array. A program to develop array technology had been initiated in 1975. Another program begun in 1977 established a dedicated facility for processing GaAsP material and assembling common module arrays. However, the program was dependent upon commercial sources for epitaxial GaAsP material.

Program Goals Set

Honeywell Optoelectronics had produced GaAsP material in the past. During 1975 and 1976, four vapor phase reactors were operated to supply GaAsP materials for digital LED watch displays. These reactors were the same type of reactor as was then commonly used to grow these epitaxial materials.

The approach for this program was to reactivate and modify one of the Honeywell vapor phase epitaxial reactors. Growth techniques were to be optimized and sufficient material was to be grown to process arrays. Assembly of arrays in the in-house facility would be used to demonstrate the quality of the materials grown. Finally, the program was used as a vehicle to develop and implement needed improvements in array production techniques.

Specific goals of the program were as follows:

(1) Modify one or more of the VPE reactors to produce epitaxial GaAsP material.

(2) Optimize material growth processes to produce material comparable to available sources.

(3) Implement standard inspection and test procedures to ensure conformation of epitaxial material to specifications developed jointly by Honeywell and NVL.

(4) Fabricate common module arrays from material grown on this program.

(5) Develop and implement improved assembly and testing procedures for array production.

NOTE: This manufacturing technology project that was conducted by Honeywell Optoelectronics for the U.S. Army Night Vision and Electro-Optics Laboratories was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The ERADCOM Point of Contact for more information is Bob Moore, (202) 394-3812.

Description of Reactor

The basic structure of the reactor used for the growth of gallium arsenide phosphide materials is shown in Figure 1. The reactor tube (chamber) proper is a quartz tube with provisions for a gallium reservoir, substrate pedestal, reactant gas entry, spent gas exhaust, and gas mixing. The chamber is heated by a multitemperature zone furnace to achieve the desired temperature profiles within the reactor. The temperature at each zone is regulated by an individual controller.

Reactant gases are supplied through a gas flow control system. The methods commonly used to control the amount of gas flowing into the reactor are (1) by restricting the flow through a capillary, or small diameter tube, or (2) by employing a mass flow controller.

The capillary tube method offers repeatable flow from one run to the next and provides a reasonably trouble-free and leak-free system. A drawback of this system is the method required to achieve graded composition. This method does not have the necessary versatility to produce either stepless grading or various composition profile grading.

In the second method a mass flow controller in conjunction with an analog programmer provides precise linear control of gas flow while ramping up or down at various rates. This allows grading to be performed in a stepless mode and allows rapid changes in grading programs.

Reactor Design and Modification

Both reactors used on this program were initially designed to operate using the capillary method of gas flow control. Early in the program, to Reactor #1 was operated unmodified. Epitaxial material was grown in this reactor. Material grown in this reactor initially had reasonable crystal morphology, but its operation was not reproducible. These results were attributed to leaks in the system and limitations of the gas control system.

Reactor #2 was modified to overcome these problems. It was redesigned to operate with mass flow controllers and automated sequencing. Additionally, improved plumbing connectors were used to eliminate leaks in the gas flow system.

Controls and interconnects for the reactor are housed in a cabinet adjacent to the reactor furnace as shown in Figure 2. Plumbing and wiring interconnects are within the cabinet; electrical and gas controls are located on the front panel.

A schematic diagram of the gas flow and control system used in the modified reactor is shown in Figure 3. All flow paths for the system are 1/4 inch stainless steel tubing. All hydrogen sources are controlled by micrometer needle valves. Pressure regulators are included in all of the supply lines to give consistent flow control. Air operated bellows valves in each line provide a fail-safe feature. In the event of loss of electrical power, all of the hazardous gases are cut off and nitrogen is fed to the reactor. Or if nitrogen is lost, all other gases are cut off.

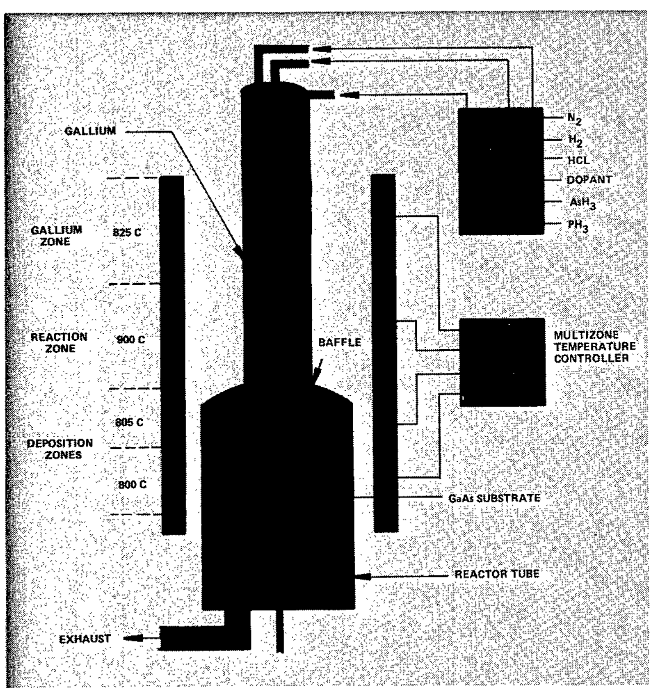


Figure 1

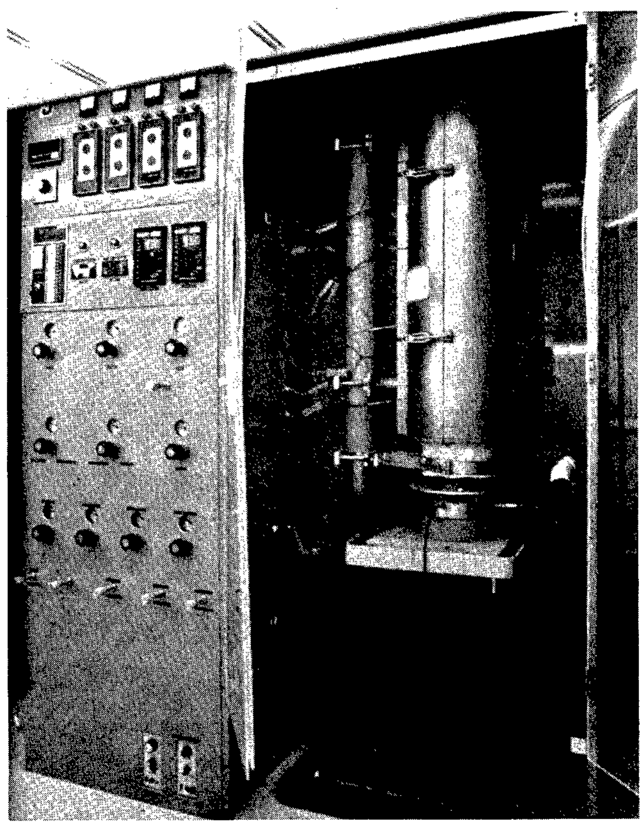


Figure 2

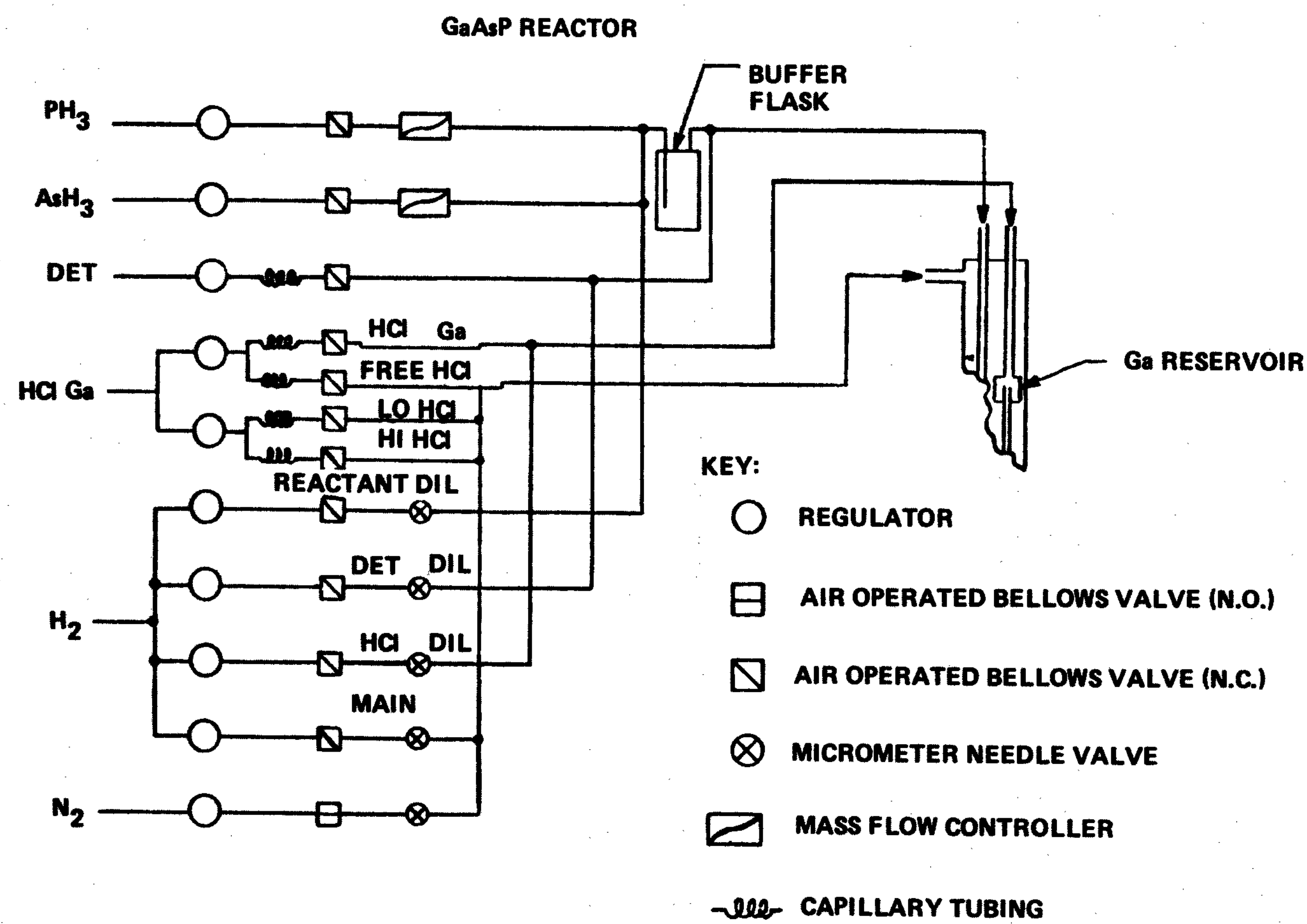


Figure 3

Reactor Facility Set Up

The complete reactor facility used for this program contains equipment required for material preparation, epitaxial growth, and characterization. A layout of the three rooms which comprise this dedicated facility is shown in Figure 4.

Up to 10 different locations can be sampled in a programmed sequence in a period of 25 minutes. Samples are fed to the monitor from each of the reactors, from the cabinets containing the arsine and phosphine cylinders, and from two points directly behind the reactor. They are analyzed by means of a gas chromatograph column. The monitor is calibrated automatically to a standard source after each eight-hour shift. Contacts on the monitor activate an alarm when the threshold limit value of arsenic (0.05 ppm) or phosphine (0.03 ppm) is exceeded.

A hydrogen detector is located next to the arsine/phosphine monitor. Two separate sampling channels are connected to the hydrogen detector. One is located in the reactor room directly behind Reactor (No. 2); another is located in the gas storage room.

Material for characterization of the GaAsP epitaxial layers is also located within the reactor facility.

Material Growth

Following epitaxial growth, slices are characterized to determine quality, composition, and doping of the epitaxial layers. Material specifications were developed for this program to provide a quantitative evaluation criteria. Tests were devised to determine conformance to these specifications.

The epitaxial structure used on this program consists of a $GaAs_{(1-x)}P_x$ layer grown on a GaAs substrate, as shown in Figure 5.Visible LED's are formed in the surface layer, which is of constant composition. For this region, x is adjusted to give the desired wavelength.

Visual Inspection

After prescreening to assure reasonably good material, slices are inspected with a low power microscope under illumination to obtain a surface reflection. A shiny reflec-

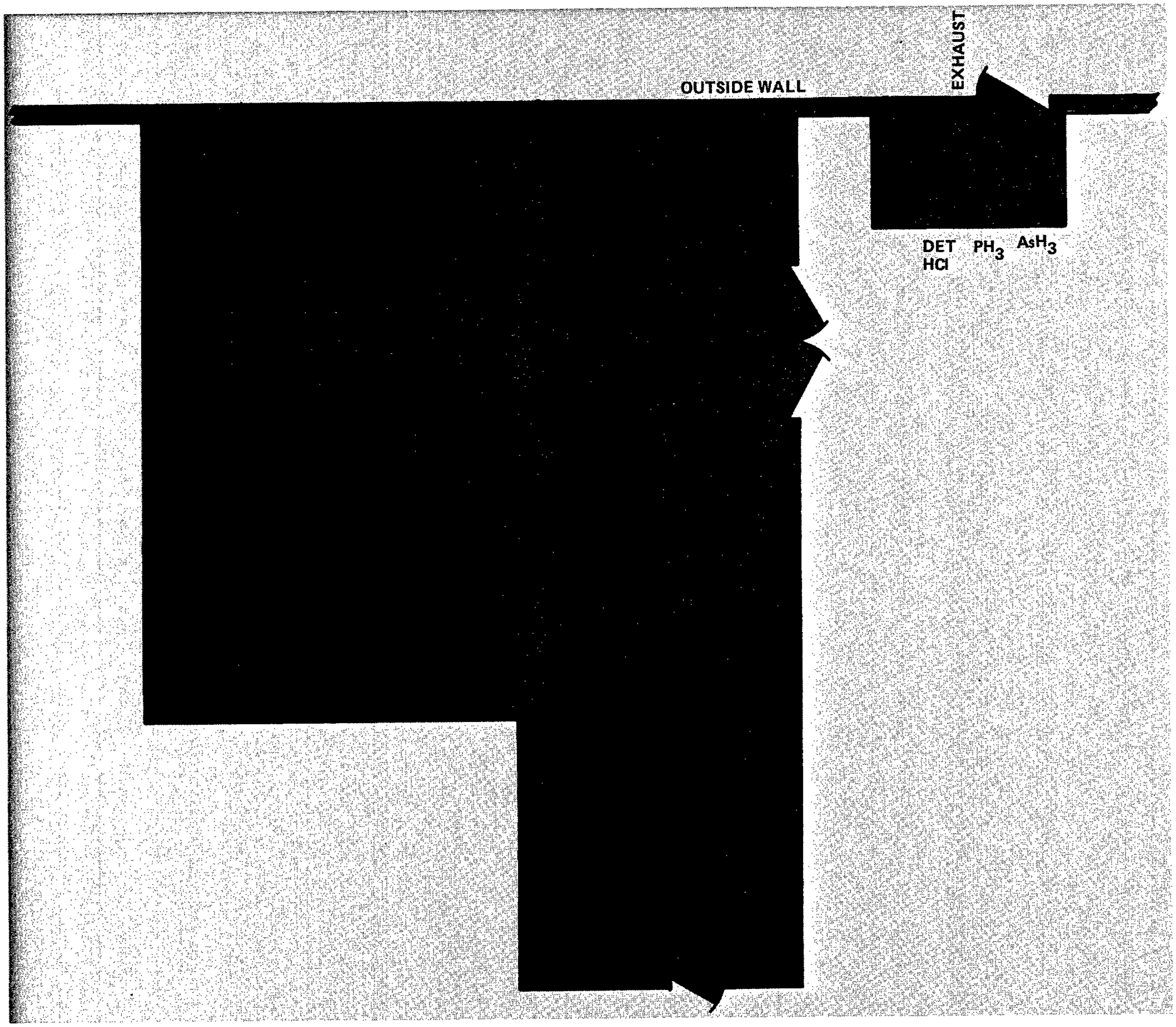


Figure 4

tion indicates good surface morphology. If dark spots or lines appear, the wafer is examined more closely under a powerful metallurgical microscope. Projections, voids, and scratches are evaluated quantitatively to determine conformance to the specifications.

Composition of the GaAsP epitaxial layer is evaluated with a photoluminescence test system. This apparatus, schematically shown in Figure 6, includes a He-Ne laser, lock-in amplifier, monochromator, and preamplifier. Correct composition is indicated when the peak photoluminescence wavelength is in the specified range.

Rough Surfaces A Problem

Material from early runs with Reactor No. 2 was not acceptable because of very rough surfaces. This was attributed in part to surges of phosphine which occurred when the mass flow controller was activated. A grading flask was added to the source line to moderate these surges. Surface and linearity of grading were substantially improved; however, there were still excessive surface irregularities. This problem was eventually solved when a defective SCR and an intermittent solenoid were identified and corrected. When good surfaces were consistently attained, the composition and doping were adjusted to meet the material specifications. Correlation between growth parameters and characterization parameters provided the basis for systematically adjusting the growth process.

Figure 7 shows photographs of cross sections for GaAsP epitaxial slices. The slice of Figure 7(a) is from an early run grown in Reactor No. 1. Discrete steps which result from switching the capillary tube are evident as distinct bands in the graded layer. The slice of Figure 7(b)

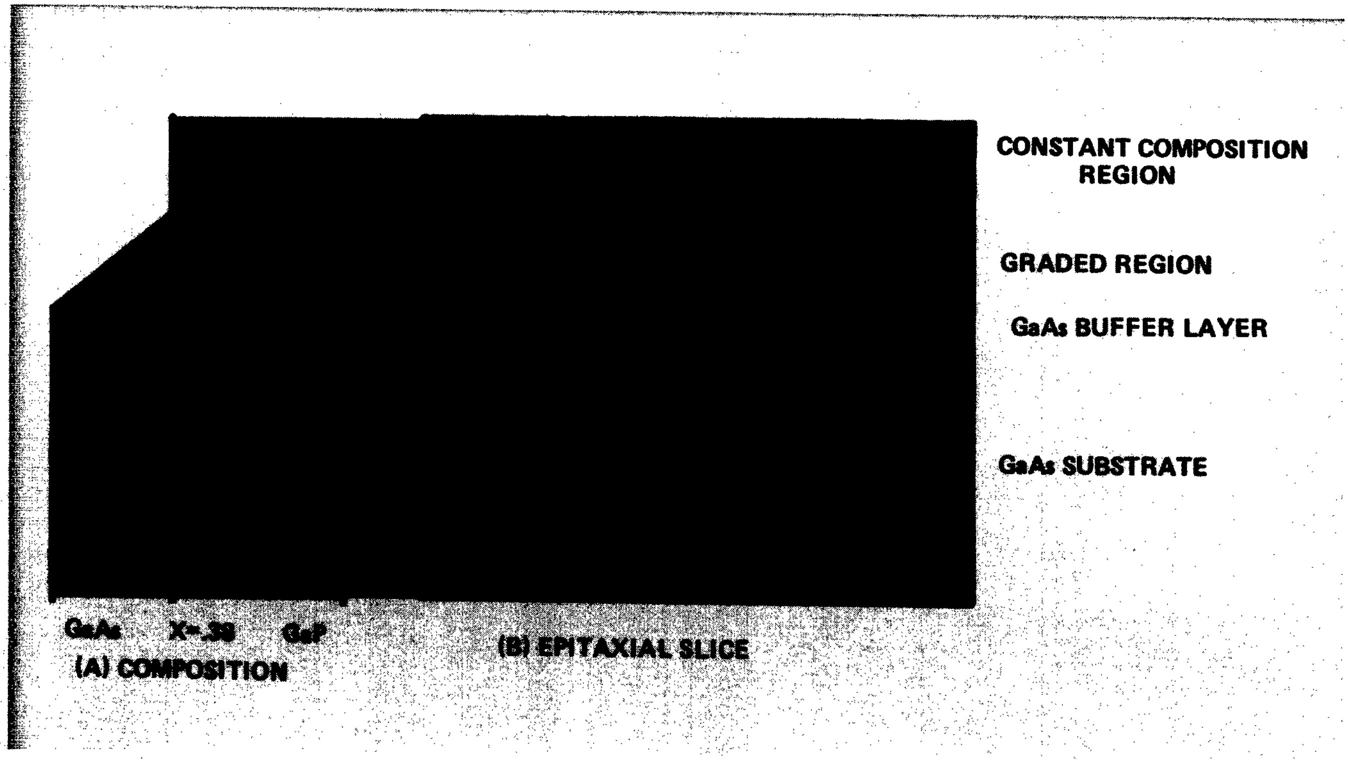


Figure 5

was grown in Reactor No. 2, modified with the mass flow controller. The smooth transition of the graded layer exhibited in this slice is desired for low dislocations and defect density.

Slice lots were processed as needed to adjust material growth parameters and demonstrate reproducible runs. When the capability to produce array quality material was achieved, sufficient epitaxial slices were grown for evaluation samples and to supply material for processing of arrays.

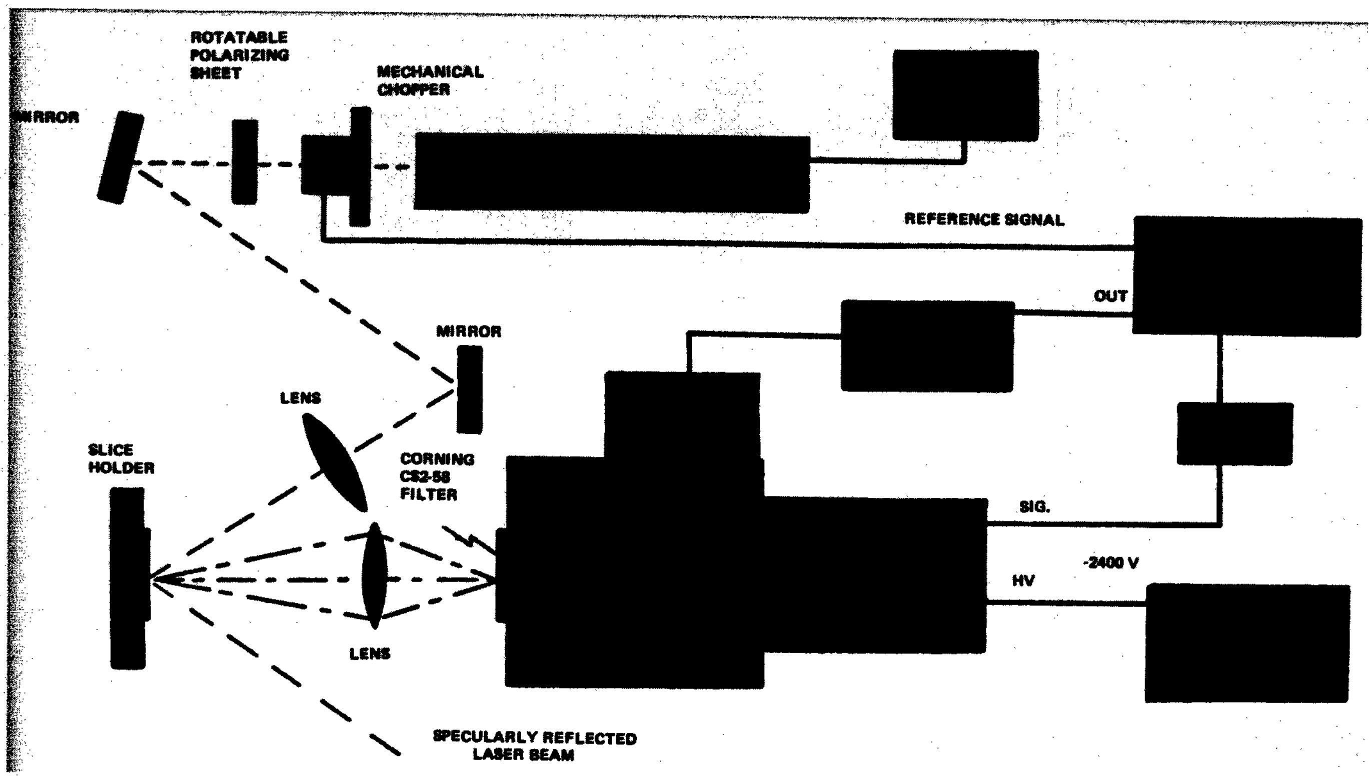
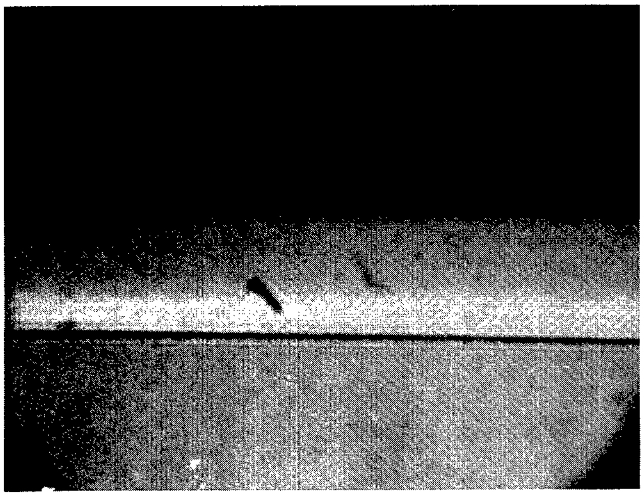
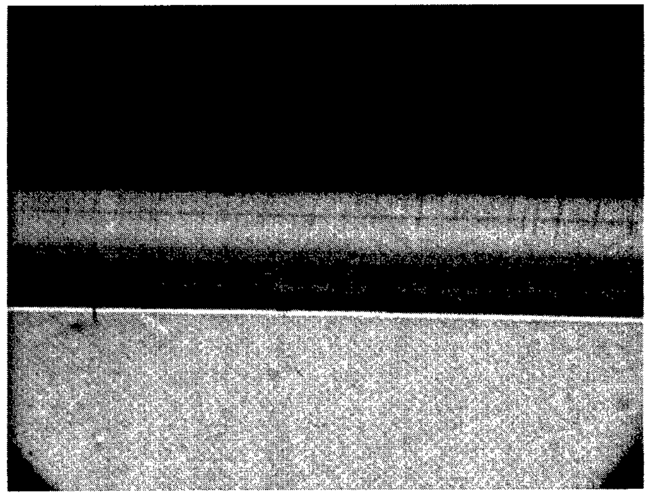


Figure 6



(a) EPITAXIAL LAYER GROWN WITH CAPILLARY TUBE CONTROL



(b) EPITAXIAL LAYER GROWN WITH MASS FLOW CONTROLLERS

Figure 7

Assembly and Test

Honeywell has a dedicated in-house facility for assembly and test of common module arrays. Following front end processing, slices are probed to test and identify good arrays. Software is available for probing both 90 and 180 element types.

When good arrays are identified at wafer probe, they are sawed out and visually inspected. The arrays are then eutectic solder die attached to a metallized ceramic header.

Common module arrays using material grown on this program were fabricated in the in-house assembly area. One each 90 element array and 180 element array which met all specifications were delivered.

Tasks Studied

This contract studied four areas of manufacturing improvement. The tasks were defined as follows: automatic resistor placement, flange focal length measurement, identification of arrays on wafer, and improved array lead geometry.

- Automatic resistor placement—an LED module with laser trimmed resistors integral to the substrate was delivered.

- Flange focal length measurement—this task was terminated when existing measurement capabilities were shown to be adequate.

- Identification of arrays on wafers—performance of automated inkers was shown to be acceptable.

- Improved array lead geometry—three LED modules of the "single sided" geometry were delivered. Implementation of this approach is optional to user activities if this version is deemed necessary.

Decontamination Unnecessary

Resistant Paint to Protect Vehicle Crews

By George Taylor
U.S. Army Tank—Automotive Command

TACOM is playing a key role in a program to convert Army vehicles from the current alkyd paint to chemical-resistant paints that will improve nuclear, biological and chemical (NBC) crew protection.

The paint conversion program begain in 1982, following an Army decision to convert its entire fleet of some 400,000 combat and tactical vehicles.

The initial goal is to start painting all new vehicles in October 1985. Then, if all goes well, the Army expects to begin painting existing vehicles during routine depot maintenance.

The TACOM effort falls under the Department of Defense's Manufacturing Methods and Technology (MM&T) program. The aim of this program is to improve military equipment and reduce its production costs by applying advanced technology to establish better manufacturing methods.

The ultimate goal of the TACOM MM&T paint project is to demonstrate the validity of using robots to paint M2/M3 Bradley fighting vehicles on the assembly line with chemical resistant paints.

According to Michael King, MM&T paint project engineer in TACOM's R&D Center, general-purpose robots are now available that can paint vehicles. King said the purpose of the Bradley vehicle demonstration is to establish a procedure that could be used to paint other Army vehicles with robots.

Camouflage Patterns Sophisticated

"One reason we are looking at robots," said King, "is that the camouflage patterns used on our vehicles are becoming more sophisticated. As a result, painting these patterns manually is now very labor-intensive. But if we can program a robot to do it, the robot can paint the pattern over and over with remarkable repeatability.

"Another advantage to a robot," he added, "is that it uses less paint to cover a surface than a manually operated spray gun does."

The new paints, called chemical agent resistant coatings (CARC), are made either from polyurethane or epoxy. They provide a barrier of protection agains toxic chemical agents that may be present in a battlefield environment.

When alkyd paint is exposed to such chemical agents, it allows them to penetrate the paint surface. So once a vehicle has been exposed, the only way to remove all the contaminant is to strip the paint by using corrosive decontaminants.

CARC Paint Nonabsorbant

But, according to King, this is not necessary with CARC paints, because the are nonabsorbant.

"The chemical agents remain on the surface," he explained. "So they can be removed with decontaminants without destroying the paint."

Following the Army's decision to make the changeover, TACOM funded two projects aimed at reviewing available CARC primers and topcoats, painting equipment, health safeguards, monitoring equipment and quality control requirements.

One of these involves the Belvoir Research and Development Center (BRADC), Ft. Belvoir, Va., which is responsible for preparing Army vehicle paint specifications.

The other project is a contractual effort with the California-based FMC Corp., the firm which produces the Bradley vehicles.

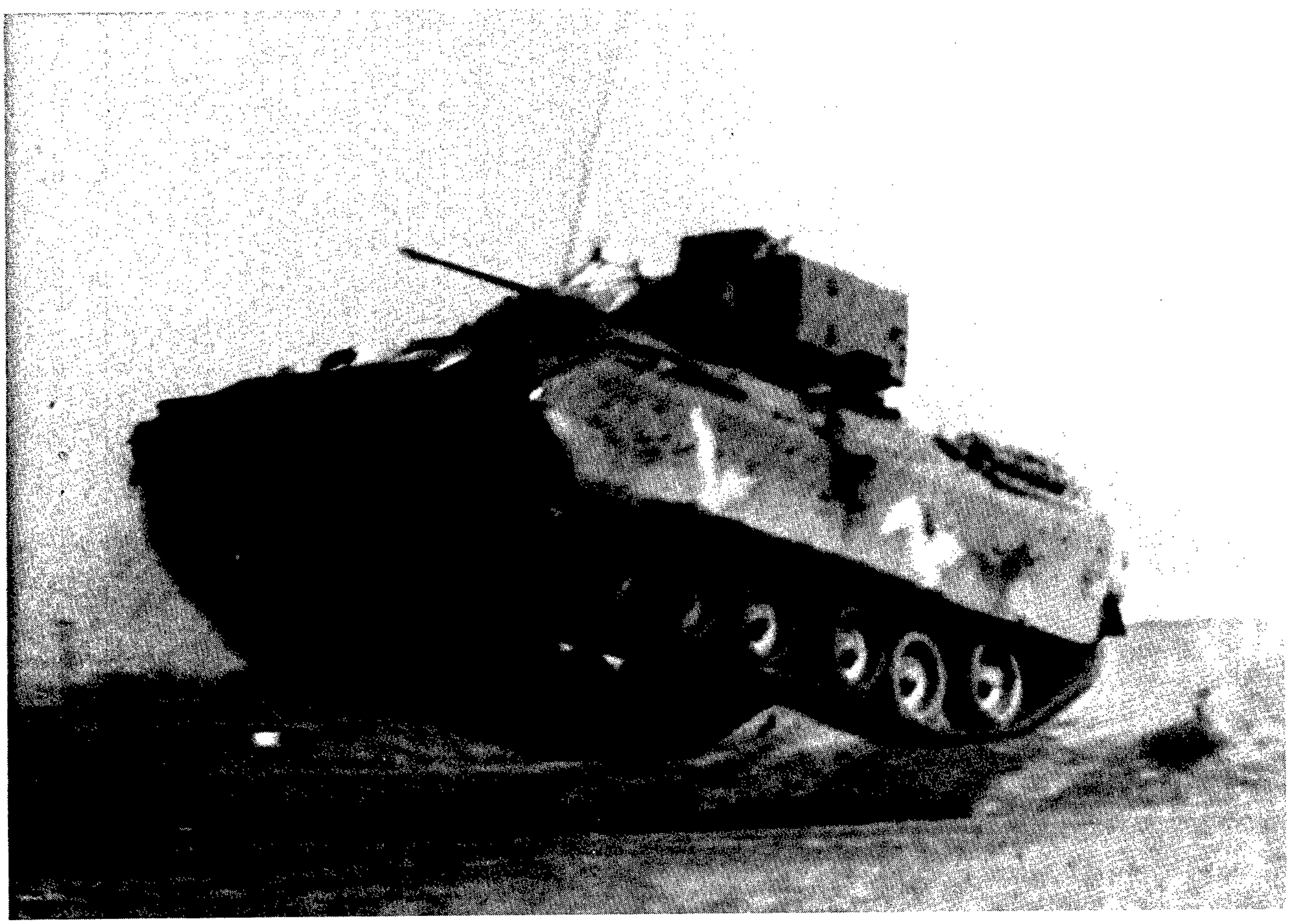
NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

EPA, OSHA Standards Met

At BRADC, engineers are testing various epoxy- and polyurethane-based paints and primers to find those that would meet Army, Environmental Protection Agency, and Occupational Safety and Health Administration requirements. This effort is not yet completed but has so far resulted in the approval of four epoxy primers, three epoxy topcoats and five polyurethane topcoats.

Meanwhile, FMC has been testing the BRADC-approved coatings under simulated production conditions. To date, the firm has chosen a CARC primer for the Bradley vehicles, but has yet to select a topcoat.

King said that once all test results are in and FMC selects a topcoat, the final step will be for FMC to install the robot system and program it for camouflage painting. He said the feasibility demonstration is expected to take place next October—one year ahead of the Army's target conversion date.



CAMOUFLAGED BRADLEY AIRBORNE DURING TESTING

Non-Planar PC Program Results

Semi-Additive Printed Wiring

ROBERT L. BROWN is a General Enginner at the U.S. Army Missile Command at Huntsville, Alabama. He is responsible for the creative direction of contractor engineers on projects such as the Non-Planar Printed Circuit Board development. He holds a B.S. in Metallurgy from Alabama University and is a Registered Professional Engineer in the State of Alabama and is credited with 8 patents. Among his many achievements are: a television X-ray imaging system and a patented method for brazing dissimilar metals.

Photograph Unavailable

ROBERT M. HANER is a Manufacturing Engineering Staff Specialist in the Advanced Manufacturing Technology Department of the Pomona Division of The General Dynamics Corp. He was the Program Manager for the Non-Planar Circuit Board Program. He currently heads a group responsible for developing manufacturing techniques for microwave components and composites. A Registered Professional Engineer in the State of California, he holds a BSME from California State Polytechnic University, Pomona, and an MS in management from the University of LaVerne.

Photograph Unavailable

Successful production of extremely accurate fine line (to 5 microns) patterns over very large areas has led to a surge of activity in microwave passive circuitry; an application in the giagahertz range is the double-spiral wound antenna developed by General Dynamics' Pomona Division for the U.S. Army Missile Command. This particular achievement was the direct result of an MM&T project and a carefully formulated development contract initiated by the Command which accurately defined the guidelines for the work.

The Non-Planar Printed Circuit Program made use of both additive and semi-additive techniques to fabricate millimeter wave antenna components, broad band spiral antennas, and an innovative cylindrical circuit board assembly.

Significant recent work in fully additive and semi-additive manufacture established the importance of distinguishing between these two methods of manufacture and the need to formulate development contracts accurately to achieve the desired results.

The Institute for Printed Circuits additive round robin did not prove that military specification test levels could be met by additive printed wiring, but it did furnish convincing proof that the military should investigate the additive potential.

In the development phase of what became two contracted projects, a gradual division of additive processes into two groups was made and were defined as "fully additive", in which circuits were pattern plated from "bareboards" with electroless copper. This group was not successful in meeting specification requirements and

Editor's Note: This article has been excerpted from a paper presented by the authors at the 16th National Technical Conference of the Society for the Advancement of Materials Processing and Engineering, October 9-11, 1984.

NOTE: This manufacturing technology project that was conducted by General Dynamics' Pomona was funded by the U.S. Army Missile Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The MICOM Point of Contact for more information is Robert L. Brown, (205) 876-2147.

until added major improvements are made in materials and methods will not be acceptable for critical military use.

The second group was defined as "semi-additive", and it readily meets military requirements as well as having specific advantages in cost and quality—leading to its increasing acceptance and use in commercial products.

Definition Clarifies Objectives

A major factor in development of an acceptable process was in the care taken in preparing the contract, mainly in establishing and defining the term "semi-additive" in such a way as to confine the term to variants of the subtractive process. All variations include the necessary steps of producing "cladding"—a uniform metal coat of minimum thickness to allow electrolytic pattern plating of the circuit lines in the developed pattern of photoresist covering the clad surface. The correct line thickness is electroformed in the photoresist pattern, the photoresist being somewhat thicker than the metal deposited. The remaining photoresist is removed, and the cladding is removed by etching. Since this cladding is only microns thick, there are only miniscule dimensional changes in dimension of the pattern—too small in many cases to be measured.

These key steps establish the process as semi-additive. Results of the contracted investigation, carried out by Hughes Aircraft Company under a MICOM contract, were fully successful in that a high resolution process evolved that met all physical tests required by military specifications, with side benefits of lower cost than subtractive and the ability to produce much finer lines and closer spacing than any other high production process. Even before the contract ended, Hughes was producing boards and hybrid base-metal substrates by the process. Independent investigations carried out at Dynamics Research Corporation have shown success in routine production of five micron lines and spaces, with no apparent barrier to higher densities; this accomplishment lends confidence to the thrust for higher densities in printed wiring.

The double-spiral wound antennas developed at General Dynamics consist of two spirals three mils wide and one mil thick, with three mil spacing between lines and nearly an inch in diameter. As such, they provide very nearly a "worst case" demonstration of the semi-additive process capability in manufacture of high-density circuits. A less extreme, but equally interesting, development out of the General Dynamics effort was a non-planar (cylindrical) printed wiring board (Figure 1). While this was not an extreme example of forming, the demonstration of potential worth of formed components, even to folded boards, is particularly impressive in terms of increased reliability and lower costs.

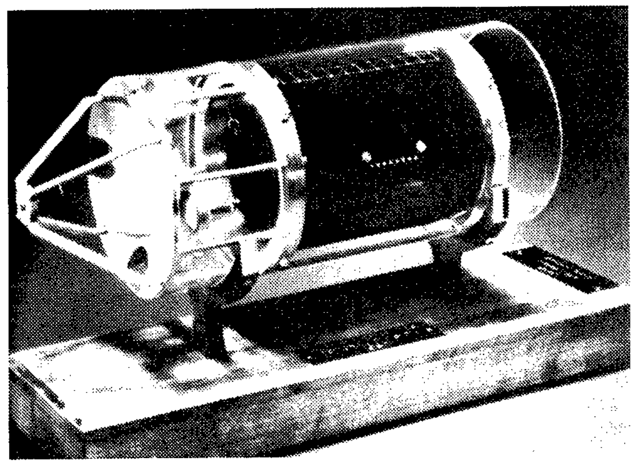


FIGURE 1. NON-PLANAR ANTENNA AND CYLINDRICAL CIRCUIT BOARD

Spiral Antenna Design

The design of the spiral antennas required for this effort was undertaken initially using an equiangular logarithmic spiral approach. Using the one-inch diameter specified and establishing that a two-arm spiral would be used in the application, the feed point dimensions were set at ±.050 inch.

With these features defined, the equation of the equiangular spiral was written. This equation was used in the computer program to generate the coordinates of the spiral geometry. The coordinates thus obtained were then used to enable the generation of a glass negative via computer-aided design using a photo plotter.

The negative was applied to a teflon/copperclad laminate, and the spiral pattern was etched in the metallization to produce a functional circuit board.

Measurement Data

The goal for the broad band spiral operation was to operate from 2.75 GHz at the low end to 18 GHz at the high end of the frequency band.

The 8-wrap equiangular log spiral functioned better above 4 GHz than below that frequency. Therefore, an

attempt was made to increase the number of wraps of the spiral while keeping the same antenna diameter. In order to do so, criteria were established that the spiral should have a conductor line width of 0.005 inch and maintain a 0.005 inch space between the adjacent wrapped elements of the spiral. A computer program was written to accomplish this, which resulted in the ability to produce a 21-wrap, two-arm spiral on the required one-inch diameter. A test assembly for this version was put together and evaluated. This antenna version operated moderately well at 3GHz.

An effort was made to evaluate a slightly larger diameter spiral.

Using the same techniques as previously described, a spiral was fabricated and assembled to permit evaluation of a 1.1-inch-diameter spiral that embodied 23 wraps. The final spiral antenna utilized 3-mil lines and 3-mil spaces.

Spiral Antenna and Balun Fabrication Sequence

The material used to make spiral antennas and baluns was a double sided copper clad teflon laminate manufactured by Rogers Corporation. The laminates were drilled with registering holes, scrubbed, rinsed thoroughly, forced air dried, and placed in an over for 5 minutes. While warm, dry film photo resist was applied.

Precision glass negatives were generated by CAD/CAM techniques (Figure 2). The spiral antenna glass negative is shown in Figure 3. The protective mylar was discarded from one side of the resist-covered spiral laminate. A polyvinyl alcohol solution was prepared with PVA, deionized water, and triton wetting agent. After filtering, it was poured over the laminate and allowed to dry.

After properly registering the laminates in their glass negatives, they were individually placed in an exposure unit. The spiral antennas and baluns were exposed to ultra-violet light.

The laminates were placed in a spray developer solution which removed the resist where it had not been exposed, leaving resist-covered circuit patterns. They were rinsed thoroughly and forced air dried.

The laminates were examined under magnification (Figure 4). The spiral circuits were too small to be touched up. If they were not perfect, they were not processed further. The parts were spray etched by warm ferric chloride, which removed copper where it was not protected by resist. The parts were immediately rinsed sequentially with water, dilute hydrochloric acid, deionized water, and then forced air dried.

FIGURE 2. SPIRAL ANTENNA NEGATIVE GENERATION BY CAD/CAM TECHNIQUES

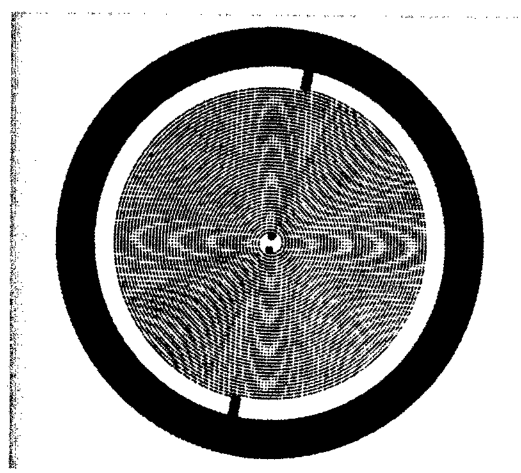


FIGURE 3. SPIRAL ANTENNA GLASS NEGATIVE

The spirals were examined to ensure sufficient etching. Small bridges were eliminated by careful use of a razor blade. The resist was stripped off and the parts were sequentially rinsed with water, dilute hydrochloric acid, water, and forced air dried. This concluded the balun processing.

In order to etch the copper off the back of the spiral laminate, resist was applied to the front only. It was etched, resist was stripped, the spirals sequentially rinsed with water, dilute hydrochloric acid, water, and forced air dried. The spirals were again examined for defects and the circuit widths were measured.

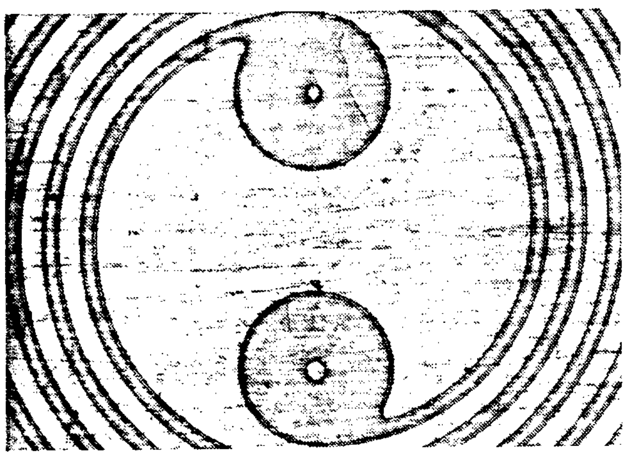


FIGURE 4. INSPECTION OF SPIRAL ANTENNAS BEFORE ETCH, MAGNIFICATION 85X

The spirals were drilled in the circuit pads and tooling, and then were gold plated and die-cut.

Electroless Copper Plating of Union Carbide Mindel A-650

After molding and machining was completed, a conductive nickel/copper/gold (or copper/gold) coating was applied onto the polysulfone parts. This plating proces was made up of several distinct subprocesses: preparation swelling, chromic acid etch, catalyzing, electroless plating, electrolytic plating, polishing, and gold plating.

The parts were annealed to remove molded-in stresses. The parts were hand washed in a mild soap solution, rinsed in a flow-through rinse, and placed onto a special rack which prevented contact between them and allowed full exposure to all chemical baths.

The polysulfone parts were immersed in a hot aqueous solution in order to remove any residual contaminates and were spray rinsed in deionized water. They were then immersed in a hot aqueous solution with work agitation and moderate stirring. This was immediately followed by immersion in an agitated flowthrough rinse.

Chromic acid etching of the swelled polysulfone could then proceed. Parts were immersed in a hot chromic acid solution which was both vigorously air agitated and ultrasonically agitated. The parts were removed from the chromic acid etchant and placed directly into an air-agitated reducer solution with immersion time depending upon part complexity. Parts were then spray rinsed and subsequently placed into an ultrasonically agitated heated reducer solution. Next, parts were immersed in a hot flowthrough rinse, then immersed in an. agitated aqueous solution. The parts then were thoroughly flow through rinsed.

The catalyzing sequence began by immersing the polysulfone parts into a hot aqueous solution followed by a turbulent flowthrough rinse. Parts were then placed into a heated prep solution with part agitation.

Next, parts were directly transferred into a heated and stirred solution. Upon removal from this solution, the part surface would appear a uniformly muddy brown. Lighter areas indicated uneven catalyzing and were minimized by the following technique: The parts were immersed in a stirred accelerator solution and parts were removed and rinsed in deionized water. The parts surface appeared a light, uniformly grey color, which indicated that the parts were properly catalyzed and ready for electroless plating.

All parts, except the hyperbolic subreflector, were then placed into an electroless nickel solution. Following a brief rinse, all parts were placed into an electroless copper solution and parts were then rinsed and air-dryed prior to electrolytic plating. Electrolytic plating began by dipping the electroless copper plated part into a furic acid solution followed by a brief flowthrough rinse. This was followed by electrolytic acid copper plating with a ductile acid coper with good "throwing" characteristics (i.e., able to adequately plate through-holes). The parts were then "bright-dipped" in a chromic acid solution, rinsed, and oven-dried.

Polishing was necessary for both the hyperbolic subreflector and the parabolic main reflector. Both parts were simply buffed to a mirror finish. The waxy polishing compound was removed by immersion in a hot alkaline cleaner, followed by thorough rinsing. The main reflector was then ready for electrolytic gold plating (the fourport waveguide required no polishing).

Prior to gold plating, the main reflectors were dipped in an acid cleaner solution and rinsed in a deionized water flowthrough rinse, activated, and given a thin coat of electroless copper. The parts were then placed in an electrolytic cyanide gold plating solution and electrolytically plated. In this manner, a conductive, protective coating with adequate adhesion was applied.

Subreflector Grid Process

An acetate filmset with the necessary artwork photographed onto its surface was formed with a combination of heat and vacuum pressure to conform to the surface of the hyperbolic subreflector. This filmset was used as

the master negative for photosensitizing the photoresist.

To begin the process, a polished and cleaned subreflector was spun on a resist spinner while resist, was applied (Figure 5). It was baked to cure the resist and then placed in a special vacuum fixture. The non-planar artwork was placed onto its surface and a sheet of teflon release film applied with vacuum tape. Vacuum was then applied to the assembly, ensuring intimate contact between artwork and photoresist; the fixture was exposed on a printer at low power. The developing process consisted of two separate immersions into ortho resist developer. The developing step was followed immediately with an isopropyl alcohol dip and forced air drying. The developed image was then cured.

The subreflectors were spray etched with a ferric chloride solution and were cleaned and inspected for dimensional accuracy. The resist was removed from the subreflector by polishing with a cheesecloth and liquid polishing compound. The subreflector was cleaned, painted, and installed onto the main antenna assembly.

FIGURE 5. APPLICATION OF PHOTORESIST

Cylindrical Circuit Materials and Process Evaluation

The basic intent of this program was to find a material/process system to produce semi-additive military printed circuit boards having a cylindrical shape.

Five potential constructions were evaluated to manufacture cylindrical single-sided, double-sided, and multilayer printed circuit boards. Extensive work was done to evaluate each processing step in the various constructions for complexity, cost, ease of manufacture, and potential for having a 95 percent confidence level of successful performance.

(1) **Glass-Reinforced Polyimide Supported Copper-Clad Substrates** capable of being bonded with B-stage glass supported polyimide adhesive layers was the first construction to be evaluated. Here, the innermost pre-etched layer would be wrapped around a mandrel and bonded with a B-staged polyimide adhesive system. Subsequent pre-etched layers would be registered with the first layer by the use of tooling pins and then bonded with adhesive layers. A unique bonding method was developed by General Dynamics Pomona several years ago to laminate composite wings and fins. This methodology was called elastomeric pressure bonding. A silicone potting resin was cast to a cylindrical shape and placed against the layers to be bonded. The layers and silicone form were restrained by the inner mandrel and outer box. The assembly was then placed in an oven, causing the silicone rubber to expand and exert uniform pressure and thus allow the B-staged polyimide adhesive to cure. Using this method for bonding eliminated the need for elaborate tooling and expensive presses. The cylindrical laminate was then ready for drilling. A special four-axis, high-speed, NC-controlled drill head was needed to complete this task. Even with the holes drilled, the elaborate and expensive vacuum and exposure equipment required to image the inner and outer layers after plating through the holes made this process costly, complex, and unreliable.

(2) A similar approach was undertaken using **Unreinforced Polyimide Copper-Clad Substrate.** These flexible layers were bonded using B-staged glass supported polyimide adhesive layers. By effectively removing half of the glass reinforcement, it was felt that conventional processing steps could be utilized. After processing, the laminate was wrapped around the mandrel. During this process the board delaminated and cracked due to the stiffness of the glass reinforcement. This approach was abandoned.

(3) An evaluation was made of **Polysulfone Copper-Clad laminate Samples.** The samples were pre-etched and thermoformed using heat and pressure over a mandrel. This system looked promising until it was found that Norplex (sole source of polysulfone/Cu

clad laminates) had decided that the market could not support their product and a production facility was never built.

(4) A fourth construction evaluated was the use of **Injection Molded Polysulfone.** By utilizing injection molding techniques, it was possible to eliminate the costly drilling step. Pins could be built into the mold to allow for "molded in holes". Expensive tooling would be required to injection mold the four individual components. Each layer would have to be additively plated, imaged, and etched in a cylindrical configuration. This processing sequence, very similar to that previously described in (1), was very complex, and costly.

(5) The evaluation led to the use of **All Flexible Materials.** Flexible printed circuits for electrical interconnections have been an important production item for many years. They have replaced mazes of "hard wiring" for assembly simplification, neatness, maintainability, weight and space reduction, and reliability, all of which are crucial in military electronics.

A description of the production steps used to manufacture a multilayer cylindrical circuit board using all flexible materials follows.

Artwork Generation

Artwork for the eight-layer cylindrical circuit board was generated using a computer-aided design system. A single circuit path was generated to interconnect each layer to a connector pad.

Cylindrical Circuit Board Fabrication

There were two types of starting materials used in the fabrication of cylindrical circuit boards. The first was a double copperclad laminate which consisted of a polyimide "Kapton" center surrounded by acrylic adhesive and copper on either side. The polyimide and the acrylic adhesive were of similar thickness. The second starting material was also polyimide bordered by acrylic adhesive.

An eight-layer printed circuit board was made by photoengraving a circuit pattern into both layers of copper and then laminating four of these etched laminates together using one sheet of bond ply between each.

Negatives of the circuit patterns were prepared for each of the eight layers. They were drilled precisely with tooling holes for use in registering the inner-layer circuit patterns (layers two through seven only) onto the laminates.

To begin fabrication of a cylindrical printed circuit board, four Pyralux sheets were mounted onto the numerical control drill shown in Figure 6 and drilled with tooling holes for subsequent lamination and drilling alignment and for registering the negatives onto layers two through seven.

FIGURE 6. NUMERICAL CONTROL DRILL

The four laminates were next scrubbed with acid cleaner and scotchbrite pads to remove oxidation. They were rinsed thoroughly, dried well, and placed in an oven. While still warm, dry film photoresist was applied using a roll laminator. Air pressure in addition to the roll pressure was used for strong adhesion. The photoresist was a light, sensitive material which polymerized upon exposure to ultraviolet light, becoming hard and insoluble in the developing solution. Hence, from this stage until developed, the resist-covered laminates had to be protected from white light except when covered with a properly registered negative.

The resist covering the tooling holes was burned out using a solder iron and tooling pins were inserted. Negatives for layers two through seven were placed over the pins and taped into position. The pins were then removed. The negative-covered laminates were next individually exposed on a light exposure unit.

The negatives and the photoresist's protective mylar were removed from layers two through seven. A convey-

orized developer containing a solution removed the resist where it was not exposed, leaving resist circuit patterns on the inner layers.

Under magnification, the inner layers were examined. Any extra resist was removed with Q-tips and Xylene. Breaks in the pattern were painted over with acid resist. The tooling holes around the periphery were masked to protect them from stretching during lamination.

Warm ferric chloride pumped over the inner layers by the conveyorized etcher removed the copper where it was not protected by the photo resist. Hydrochloric acid automatically rinsed off the hydrochloric acid. The resist's mylar was discarded from layers one and eight. They were examined to ensure there were no broken circuits.

The photoresist was stripped off and the circuits were dipped in dilute hydrochloric acid and scrubbed again with acid cleaner and scotchbrite pads.

Using a straight edge and razor blade, the inner layers were trimmed according to preimaged guidelines, which had been placed so as to ensure proper fitting together of the ends when bonded into a cylindrical shape. The bond plies were trimmed at the same time, using the inner layers as templates. They were wiped clean using alcohol and a cloth.

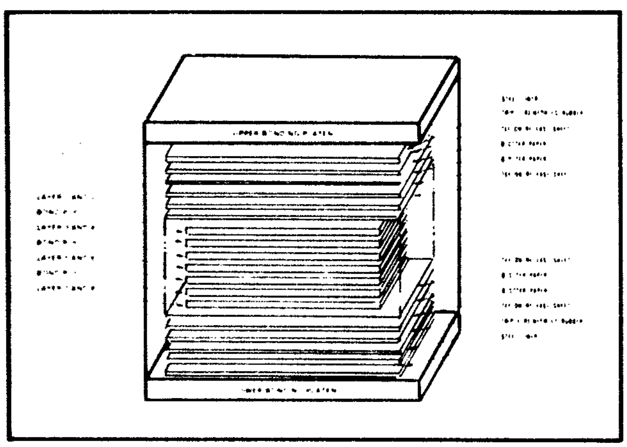


FIGURE 7. LAMINATION LAYUP

Teflon placed between the layers allowed air and moisture to escape while they and the bond plies were baked.

Immediately after removal from the oven, the lamination package was layed up as illustrated in Figure 7. It was registered together using the holes previously drilled. The mylars were removed from the bond plies.

It was found that the triple reinforced rubber/blotter paper combination provided excellent results. It was solf enough to provide adequate pressure on both the areas containing copper circuitry and the thinner areas where the copper had been etched off. The blotter paper provided excellent dimensional stability, preventing stretching. Also, smooth blotter paper gave rise to a smooth surface in the region used to bond the printed circuit board into its cylindrical shape.

The package entered the press cold so as to allow air to escape before bonding occurred. It was cooled under pressure to ensure good lamination. To prepare for drilling, the laminated board was registered onto the numerical control drill using the tooling holes used during the lamination layup. A coupon pad was drilled and then X-rayed to check for registration. If the coupon was not centered, the board was remounted, the drill alignment adjusted, a hole drilled in another coupon, X-rayed again, and the sequence repeated until the drill was properly aligned. When a hole was centered, the board was drilled on the circuit pads, the connector pads, and the connector mounting pads.

Before copper plating, the holes needed to be cleaned. The board was rubbed gently with wet sandpaper to remove protruding copper caused by the drilling operation. It was then baked and immediately plasma desmeared to remove any acrylic adhesive inside the holes caused by the drilling operation. The plasma desmearing unit is shown in Figure 8.

The board was next electroless and electrolytically copper plated using standard procedures. The procedure for imaging the outer layer circuit patterns was the same as for imaging the inner layers. The board was scrubbed

FIGURE 8. PLASMA DESMEARING OPERATION

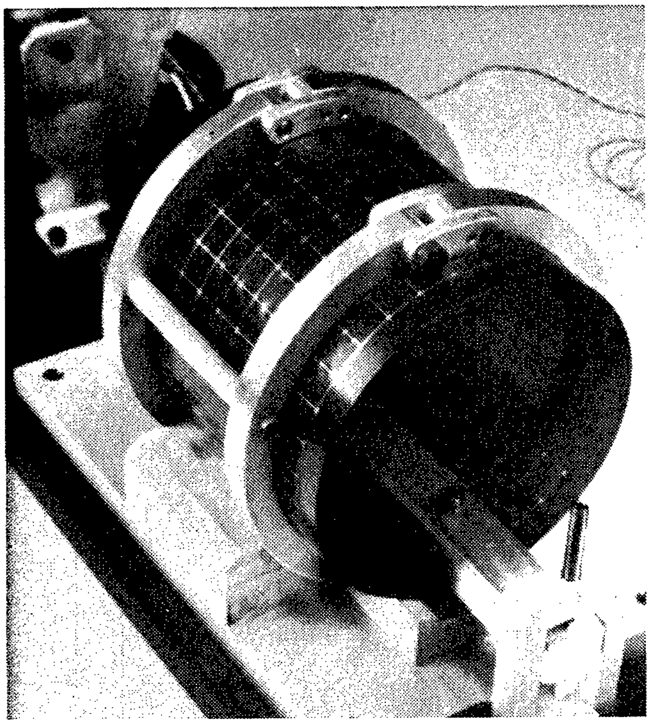


FIGURE 9. CYLINDRICAL CIRCUIT BOARD IN BONDING

to remove oxidation, placed in an oven, laminated with dry film photoresist, aligned with the proper negatives, exposed to ultraviolet light, developed, touched up, etched, stripped, and scrubbed.

After trimming the printed circuit board to its finished part dimensions, it was ready to be bonded into a cylindrical shape. A strip of cast acrylic adhesive material was cut out. The bonding surfaces of the circuit board were cleaned with alcohol and the ends were not touched after being cleaned. A soldering iron with a flat tip was used to tack the adhesive strip to the bonding end of the circuit board.

The circuit board needed guide holes punched into each bonding end for insertion into the bonding fixture. A fixture held the bonding end secure and a punch was run through each guide hole on the fixture to create these holes. After the holes were made, the circuit board was placed into the bonding fixture (Figure 9). Heat was applied along the bonding edge via a heater element to complete the bonding cycle. The temperature was monitored and controlled by a temperature controller box. When the bonding was complete and the circuit board cooled down, it was removed from the bonding fixture. The board was then ready to have its connector installed and to be continuity checked.

The connector was installed and its pins were soldered to the board, then the solder points were cleaned with alcohol to remove any flux remaining on the pins. A continuity test box was hooked up to the connector. A switch on the test box allowed the user to select any one of the eight layers for testing. A probe connected to the test box allowed the user to touch any desired point on the circuit board, and if the continuity was good a light on the test box illuminated. If the board had good continuity it was ready to have components placed into it.

Several different types of multilead components and resistors were installed (Figure 10). The components were inserted on the interior of the circuit board so that their pins would extend through the board to the exterior for easy placement of solder paste on each pin. It took about five hours to place all of the components onto the circuit board.

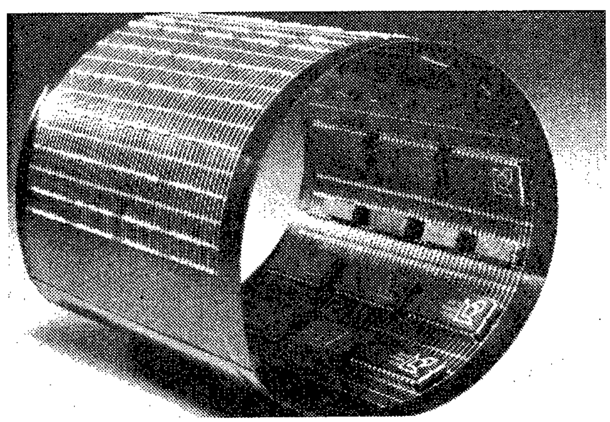


FIGURE 10. CYLINDRICAL CIRCUIT BOARD WITH MULTI-LEAD COMPONENTS

A turbocharger air compressor that applied a preset air pressure to a syringe filled with solder paste was used to place the solder paste onto each component lead. It took about two hours to coat fourteen hundred component leads with solder paste.

The circuit board was placed into a fixture that prevented the board from deforming when it was placed into a vacuum temperature box to remove any absorbed water from the polyimide material. The vapor phase solder machine (Figure 11) performed the soldering in one minute, fifteen seconds. The machine had three steps. First, the basket containing the circuit board in its fixture was lowered to a preheating stage so thermal shock would

FIGURE 11. VAPOR PHASE SOLDER MACHINE

not occur. Second, the basket was lowered into the soldering vapor, then pulled up to the preheat stage to allow the vapor to condense and go back into the vapor solder chamber. The basket was pulled back up to its stowed position and when the circuit board had cooled down the board was removed from the basket and holding fixture.

The board with components installed was placed into a cleaning tank to remove the solder flux and any other contamination. This completed the cylindrical circuit board fabrication.

References

(1) Final Report for Contract DAAH01-76-C-1100, "Semi-Additive Processes for the Fabrication of Printed Wiring Boards", Hughes Aircraft Corp., Fullerton, CA, for MICOM, 1978.

(2) L. R. Volpe, "Metriform Fabrication Spurs Development of High Density Circuits", Electronic Packaging and Production, May 1981.

(3) Final Report for Contract DAAH01-81-C-A777, "Manufacturing Methods and Technology for Non-Planar Printed Circuit Boards", General Dynamics Pomona Division, Pomona, CA, for MICOM, 1983.

Brief Status Reports

Project 6098. Production of Special Armor Steel. Steel plate from 3/16 to 2 in has been successfully rolled to the desired texture. Some problems with flatness still exist to be resolved. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6079-01. Monocrystal Alloy for High Pressure Turbine Blades. Monocrystal application analysis has been initiated for cooling air trade off, property verification and stress analysis. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6107-02. Adaptive Fluidic Damper. The manufacturing process, alternate materials and an economic analysis have been completed. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6107-03. Organic Composite Road Wheel. A composite roadwheel was designed using glass and graphite fibers in an epoxy matrix. The current aluminum roadwheel design is being compared to the composite wheel to determine adequacy. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6121. CAD/CAM for the Bradley Fighting Vehicle. Program budgets and schedules completed. Procurement of a robotic system has been initiated. AT-ARC hardware and software compatibility has been completed. Vision subsystem procurement has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3592. Improved Graphite Reinforcement. Temperature and line speed were varied to optimize the graphitization step. Best strength and modulus values were found. The contractor is preparing the final technical report after providing 20 pounds of fiber. For more information, contact Richard Green, TROSCOM, (314) 263-3353.

Project 3083. MM Wave Communications Front End Module (CFEM). Microwave associates designed the mixer. IF amplifier, detector, isolator and voltage controlled oscillator for the millimeter wave command post radio. A lock-on module is being considered. Design of the pin diode attenuator, coupler and filter continued. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 5005. Computer Aided Design for Cold Forged Gears (Phase I). The computer program, Geardi, developed in this phase corrected tool geometry for elastic deformation, modify geometry for temperature differentials, and computer wire electrical discharge machining paths for manufacturing both the die and punch. A spur gear, Eaton part number 27952, and a helical gear, Eaton part number 49221, were approved for forging. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5067. Plastic Battery Box. Modifications to battery box lid are being made by contractor. This is necessary to comply with multi-temperature stress test. This additional testing was requested by DRSTA-G for the 5-ton vehicle. Test results may affect TDP. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5075. Military Elastomers for Track Vehicles. Procurement actions and testing arrangements are being made for T156 (Abrams M1) track shoes. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5082. Flex Machining System (FMS Pilot Line or TLV Comps (CAM) (Phase V). Suspension components manufacturer was provided. This effort included modeling batch mode operations, alternate production strategies and capacity. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5083. Upscaling of Advanced Powdered Metallurgy Processes (Phase 3). The dies for the M2/M3 gear have been designed by the interactive computer program. The funds from this project have been utilized to monitor another Phase 4 project. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5090. Improved and Cost Effective Machining Technology (Phase V). Contractor has selected 5 of 6 candidate components which will be used to show feasibility of non-traditional machining processes application. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6054. Advanced Metrology Systems Integration (Phase II). All Task for Phase I have been completed, and the guidelines for future IMS have been established. However, the simulation model computer software program requires modification, since it is not compatible with TACOMs prime computer system. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6059-13. Metal ARC Spraying. Investigation of processes and process specification development are complete. Preliminary process evaluation has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6059-17. Pre-Paint Cleaning System. Literature survey has been conducted and project coordination has been established with BRADC. Test specification has been established. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6059-19. Squeeze Cast Road Wheels. A turret hatch has been designed suitable for the squeeze casting process. Specification evaluation has been initiated. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6079-02. Rapidly Solidified Rate (RSR) Nickel-Base Superalloy. Under components qualification, component inspection and evaluation has been started. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6079-06. Automatic Deburring of Engine Components. Review of the state-of-the-art of automated deburring units has been completed. A robotic deburring approach has been selected. Avco Lycoming is currently selecting the robotic unit. Requirements are to deburr as many components as practicable. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6090. Tooele Army Depot Productivity Improvement Program. The majority of the preparatory work for the depot program has been completed. The project is now awaiting further funding enabling Phase I to begin. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6095-03. Surface Treatment and Cast Hardening of Steel Components. Effort to date has been CAD geometric modelling of coil design for candidate gears. Coils, tooling, and test gears are being procured. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3115-34. Improved On-Site Service. Air speed calculations produced from the output of a differential pressure transducer passed through a voltage to frequency converter, counter, and microprocessor have been completed. This software has been committed to EPROM for use. Procurement has started on air speed modifications. A quantity of differential pressure transducers is being purchased. Portions of the hydraulic pressure standard work has been completed. Evaluation of the pressure transducers is underway. For more information, contact K. Magnant, TMDE, (205) 876-2891.

Project 6099. Manufacturing Methods for Specialized Armor Materials. AMMRC, AMCCOM, and PBM have progressed in the areas of materials, processes and facilities toward realizing the program objective. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 6107-01. Computer Manufacturing From High Strong Lightweight Ferrous, Non-Ferrous and Material Matrix. Two contracts were awarded. One has completed the DIN design, which consists of DWAL20 tubes with a steel jacket. The other has completed the casting design for the pins and is modifying the loom for weaving the silicon carbide fibers. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3115-17. Dynamic Electrical Measurement Standards. A modular pulse circuit has been evaluated. The circuit promises to be very versatile since it can be pulse operated, continuously modulated, or operated in a static forward biased mode. For more information, contact K. Magnant, TMDE, (205) 876-2891, F. Seeley, TMDE, (205) 876-2666, or L. Bowling, TMDE, (205) 876-8417.

Project 3115-25. Basic Metrology Standard for Use in Wide-Ranging Environments. Additional wiring has been installed so that voltage of references placed in an environmental chamber may be monitored. This will be used to measure the response of the reference to varying temperature and humidity conditions. Characterization of various commercial solid state voltage references devices continued using the automated system. It has been concluded from measurements made thus far that a filter on the output is required in order to achieve dependable results. For more information, contact K. Magnant, TMDE, (205) 876-2891, F. Seeley, TMDE, (205) 876-2666, or L. Bowling, TMDE (205) 876-8417.

Project 5052. Army Engineering Design Handbook for Production Support. Continued work on 706-158 and 159, dynamics of ballistic impact, parts I & II, and 706-199, development guide for reliability, part 5, contracting for reliability.

Project 4005. Water Jet Material Removal System Phase II. The system has been fabricated and delivered to RRAD. One of the pump motors was found to be defective. The motor was replaced by the contractor and acceptance tests will be performed.

Project 4005. Water Jet Material Removal System Phase II. The system has been fabricated and delivered to RRAD. One of the pump motors was found to be defective. The motor was replaced by the contractor and acceptance tests will be performed. For more information, contact Mike Ahearn, DESCOM, (717) 263-6591.

Project 3115-19. Submillimeter Wave Standards. This task has been completed. This system is now qualified as a measurement system for use in certifying standards for Army primary calibration laboratories. For more information, contact K. Magnant, TMDE, (205) 876-2891, F. Seeley, TMDE, (205) 876-2666, or L. Bowling, TMDE, (205) 876-8417.

Project 3115-01. Josephson Effect Voltage Standard. A one PPM voltage standard was delivered. Problems were encountered during initial operation of the system. Liquid nitrogen used to precool the Dewar solidified at the bottom of Dewar preventing insertion of the Josephson junction probe. Testing of IPPM voltage standards continued during this reporting period. Problems still exist in the production and selection of appropriate Josephson-junction devices. The problems are peculiar to individual devices and may cause non-vertical steps. For more information, contact K. Magnant, TMDE, (205) 876-2891.

Project 2642. Advanced Penetrating Radiation Technology for Product Evaluation. Speed and sensitivity of low silver films have been compared with conventional industrial radiographic film. Exposed curves are being evaluated for the films. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 3411. Non-Planar Printed Circuit Boards. All work has been completed and a final status report has been received. Multilayer cylindrical circuit boards and a microwave dish antenna were used as samples for developing the manufacturing processes. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5024. Gear Die Design and Manufacturing Utilizing Computer Technology (CAM). The movie on CAD/CAM of spiral bevel gears has been approved. A 16.5 inch spiral bevel gear has been selected for forging. The spiral bevel gear program, SPBEVL, was executed to predict settings to produce the EDM electrodes to cut the forging dies. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5053. Fabrication Techniques for Hi Strength Structural Ceramics. AMMRC has initiated efforts to hot press composites of SI3N4 and varying layers of ZR02 cloth. Adiabatic diesel engine components (Phase II). Contractor has initiated efforts to optimize material and manufacturing technologies. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5054. Laser Surface Hardened Combat Vehicle Components. Pilot heat treating of test samples is complete. Samples have been delivered to TACOM for evaluation and marking. Laboratory testing is complete. Field testing has been initiated. Laser heat treating of hardware is complete. Hardware testing is complete. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 4575. Laser Welding Techniques for Military Vehicles. Contract awarded. Currently addressing porosity problem through deoxidants and beam oscillation. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 3094. Communications Technology Techmod for JTIDS. Collins developed preliminary specs for a work cell for placing surface mounted components on printed circuit boards. Also wrote a spec for data and distribution system. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 1051. Replacement of Asbestos in Rocket Motor Insulations. Kevlar filled propellant grain inhibitors proved to be equal to asbestos filled inhibitors. Kevlar filled smokeless insulators were tested and are being analyzed. Work is leading to the test phase in the other work. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1060. Electrical Test and Screening of Chips. The machine structure and architecture is so devised as to allow implementation as a stand alone or a host operated system. The internal controllers are partitioned into logical work stations. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1086. Cobalt Replacement in Maraging Steel-Rocket Motor Components. Scale up to 14 inch diameter and concept demonstration have been started. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1089. Integral Rocket Motor Composite Attachments. The contract was awarded to Hercules Inc., Bacchus Works, Magna, Utah. Structural requirements determination, component selection, and static/dynamic analysis have been completed. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 1121. Missile Manufacturing Productivity Improvement Program. A scope of work was prepared and contract documents are in the approval chain. Meetings have been held with Navy and Air Force. Martin Marietta will study its plant and determine what MMT and business system must be implemented for hellfire production. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3263. Printed Wiring Boards Utilizing Leadless Components. Hughes optimized methods for attaching leadless chip carriers (LCC) to printed circuit boards. Tasks were pretinning, soldering, bonding, conformal coating, and testing. All work is completed. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 3376. Testing of Electro-Optical Components and Subsystems. All technical work has been completed. Final technical report draft has been received and approved. For more information, contact Bobby Austin, MICOM, (205) 876-2147.

Project 5071-71. Improved Copper Crusher Pressure Gages. The internal ballistics division completed its analysis of the gage parameters using finite elements and prepared a gage design. The design was modified by mtd to fully satisfy known requirements. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-76. Gamma Dosimetry Improvement and Modernization Program. The basic production gamma dosimeter was changed to a calcium fluoride chip from lithium fluoride powder. An automated gamma dosimetry data base program for data storage and retrieval and report preparation has been completed. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-01. Acceptance Test Procedures. The central library for the total ATP program (ammunition, armor plate and weapons) was maintained. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-43. Test Automation. This subtask identified procedures/equipments needed to automate existing RF simulators and RF monitors. Results are reported in JPL report (JPL D1052), October 83, subject DVAL/GPRS Automation and integration. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 5071-57. General Purpose Bit Slice Microcomputer. This project has provided knowledge in bit-slice hardware technology, microprogramming, and minicomputer interface applications. For more information, contact William Deaver, TECOM, (301) 278-3677.

Project 2962. Automation of 65 Degree C Propellant Surveillance Test. A Textronix computer with display terminal, together with essential peripherals such as a graphics copier were produced. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2968. Investigation of Scan Photoacoustic Microscopy For Ceramics Inspection. A statement of work has been prepared for the demonstration of the scanning photoacoustic microscope (SPAM) for detection of surface and near surface defects in structural ceramic material. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2972. Capillary Gas Chromatographic Test of Army Solid Propellants. The results of this effort have demonstrated that the capillary gas chromatography is a significant improvement over packed column gas chromatography. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2980. Portability of Test Software for VHSIC Chips. The contract was awarded. Work has started on reviewing the VHSIC chip and test software specifications to determine commonalities. ATLAS, PASCAL and ADA languages were reviewed for suitability as common intermediate test description language. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2981. Fluidic Power Supply Acceptance Tester. The high pressure acceptance tester breadboard work has been completed. All of the purchased components have been received. The computer has been integrated with the prototype pneumatic system. The trajectory data software is complete. For more information, contact John GAssner, AMMRC, (617) 923-5521.

Project 3001. New Acceptance Tests For Chemical Agent Resist of Urethane Paints. A contract for the conduct of this effort was awarded. A literature search is underway by the contractor and techniques to prepare thin films evaluated. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 3006. Acoustic Emission Monitor/Control of Gun Tube Straightening. The gun tube bend tests were completed. Investigated the benefits of using noise analysis equipment. Performed on-line, full-scale testing. Established AE parameters to be applied to production cannon tubes. Completed the full scale testing. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 3010. Digital Image Amplification X-Ray System. Two inert standard were designed and fabricated. Multiple X-rays were taken and analyzed to determine the defects within the inert fillers. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 5064. Light Weight Saddle Tank (Phase III). Leak development at return line which has delayed testing at APG. New tests were requested by potential users prior to their implementation. New testing to satisfy federal motor safety regulations continue. Potential users who would implement project results are the interested parties. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 5067. Plastic Battery Box. Modifications to battery box lid are being made by contractor. This is necessary to comply with multi-temperature stress test. This additional testing was requested by DRSTA-G for the 5-ton vehicle. Test results may affect TDP. For more information, contact Don Cargo, TACOM, (313) 574-8709.

Project 7465. Advanced Composite Sensor Support Structure (ACS-3). Contract was awarded to McDonnell Douglas Astronautics Company. A critical design review will release work on tooling fabrication. For information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 3068. Increase Productivity of Varactors and Pin Diodes. Co-planar contact-side via-hole GAAS varactor chip design is abandoned. Process now incorporates thermal epitaxy and ion implant. Deep level trap. Measurement equipment is set up. Problems with the oxide/nitride passivation process still exist. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 3073. Tactical Graphics Display Panel. GTE resolved high line resistance and shorting problems for 10x12 in. thin film electroluminescent display panels. Brightness achieved is between 60 to 100 footlamberts. Exerciser was completed and demonstrated on a CRT. New insulator will be tried. For more information, contact Al Feddeler, CECOM, (201) 535-4926.

Project 2611. Sorption of Agents on ASC Whetlerite. Adsorption isotherms were determined for ASC whetlerite charcoal at four levels of impregnation, for a production lot of impregnated charcoal, and for a standard charcoal of known surface area using two independent methods. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 7412. Infrared Detector for Laser Warning Receiver. Perkin-Elmer Corporation made 86 indium arsenide IR detectors. Processes include diffusion of zinc-diarsenide, lapping and plating wafer backside, chrome-gold plating of frontside, masking, etching an interdigitated pattern, and mounting and wiring to header. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7415. MMT T700 Blisk Repair. Two welding operations have been defined for this repair program, plasma and TIG. Coupons for high cycle fatigue and corrosion tests have been fabricated. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7427. Attack Helicopter Productivity Improvement (API) Program. Booz Allen and Hamilton hired by Hughes as a consultant. A top-down analysis is in process. Existing cost, schedule and quality drivers analysis was completed. An assessment and identification studies are in process. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7433. MMT—IPI PGM—Bell Helicopter, Inc.—AHIP. Phase I work is complete. Ten major thrust areas were identified. The as-is writeups have been completed and the to-be items are being reviewed by the Bell upper management. Six initial projects are being conducted on the EA model. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 2894. Residual Stress Determination by Acoustic Wave Velocity. Evaluated the ultrasonic interferometer. The interferometer will be used for determining the third order elastic constants under applied stress conditions which are required for residual stress determinations. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 7298. High Temperature Vacuum Carburizing. Modification to the AISI gear steel vacuum carburizing has been completed. Components have been remanufactured, heat treated and shipped to Boeing-Vertol for evaluation. Metallurgical evaluation of all the specimens is still on-going. For more information contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7371. Integrated Blade Inspection System (IBIS). Completed the work on the IRIM flaw and airfoil section including the performance and validation test plans. IRIM hardware including high speed image acquisition and manipulation equipment was acquired. For more information, contact Fred Reed, (314) 263-3079.

Project 7382. Low-Cost Composite Main Rotor Blade for the UH-60A. A new, improved, single piece mandrel was evaluated and found to reduce manpower time. Fabrication of full sized blades, Phase 2, was initiated. Work was conducted in-house and consisted of fatigue tests on a ballistically damaged blade section and extensive negotiations with the contractor. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 7389. Production of Aluminum Airframe Comp (Superplastic Forming). Detail design refinement and tool design is completed. Tools are fabricated and proven. Drawings are released. For more information, contact Fred Reed, AVSCOM, (314) 263-3079.

Project 2834. Improved Track Pin Shot Peening Inspection. The implementation phase has been completed. It consisted of installation of automated X-ray diffraction equipment. During implementation, it was found necessary to design a new jig more suitable for production environment for holding track pins. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2895. NDT of Advanced Composite Structures for Bridging. A laboratory model of a hand scan ultrasonic c-scan system optimized for bridging application has been assembled. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2926. Testing of M55 Detenator Stability Sensitivity and Output. An automated system for testing M-55 detonators stab sensitivity and output was designed. Orders have been placed for the required equipment. Components which can not be purchased have been designed and fabrication has started. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2932. Assessment of Glare/Scatter in Fire Control Optical Systems. A survey of glare measurement techniques was undertaken. A number of techniques were identified and will be considered for this effort. Also, a visit was made to EAstman Kodak Corporation to discuss glare techniques used. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Project 2934. Application of X-Ray TV System for Diffraction Patterns. Experiments were conducted to determine the optimum hardness threshold values. Standard vickers hardness measurements were made on flat and curved specimens and they compared favorably with those computed from the X-ray diffraction image. For more information, contact John Gassner, AMMRC, (617) 923-5521.

Electronic Dynamometer Simulation

Power and Inertia Simulator Simplifies Testing

By George Taylor
U.S. Army Tank—Automotive Command

TACOM is funding an MM&T program aimed at equipping the Mainz Army Depot in West Germany, which rebuilds vehicles, with a computer-controlled dynamometer system that will for the first time electronically simulate vehicle inertia.

In dynamometer testing, a dynamometer measures an engine's mechanical power by generating electrical resistance against its rotation to simulate the load of a moving vehicle.

Though this kind of testing is effective, up until now it has had one shortcoming: with current test equipment it is possible to produce only a limited amount of inertia. This is done by mounting a heavy flywheel to the dynamometer which, when rotated, simulates the inertial load of a vehicle.

The problem with this approach is that it is not economically practical for simulating tanks and other heavy vehicles, because the flywheel's weight must equal the weight of a given vehicle to simulate its inertia.

Also, the weight and size of such a flywheel would cause unwanted oscillations in the test equipment that would be difficult to eliminate.

Thus, conventional dynamometers for the most part simulate only vehicle rolling resistance and do not produce the inertial forces that occur during other conditions such as uphill driving and braking.

More Practical Economically

The new dynamometer system, called the Power and Inertia Simulator (PAISI), can be tailored to simulate the inertial loads created by any vehicle, regardless of its weight.

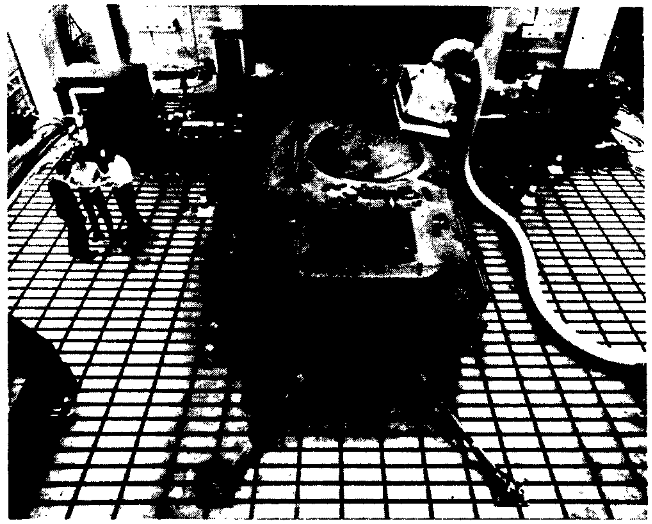
The PAISI was developed jointly by the West German-based Brown Boveri Corp. and the University of the German Armed Forces, in Hamburg.

It comes in a variety of test-rig versions. Each is designed to test either a specific type of major vehicle component or system—such as a transmission or a brake system—or a complete vehicle.

According to Donald Cargo, PAISI coordinator in TACOM's R&D Center, the version to be installed at Mainz is a tracked vehicle performance test rig.

"This system," he said, "not only simulates vehicle rolling resistance, but also the effects of mass inertia encountered while accelerating, coasting, braking, ascending and descending hills and turning."

The PAISI consists of a vehicle test stand—comprising two dynamometers and a 1,600-ton foundation that supports and stabilizes the test vehicle—and a computerized electronic control system.



BRADLEY HULL RIGGED FOR PAISI FEASIBILITY TESTS AT THE UNIVERSITY OF THE GERMAN ARMED FORCES, MAINZ, GERMANY

In operation, a test vehicle is first moved into position and clamped to the foundation. Technicians then remove the vehicle's tracks and couple one dynamometer to each track drive sprocket.

Throughout the ensuing test, an operator "drives" the vehicle. That is, he accelerates, shifts gears, steers and brakes the vehicle, while the electronic control system makes preprogrammed adjustments to the dynamometers' speed and torque output to simulate the various inertial effects.

The electronic controls can change the speed and torque of each dynamometer independently, thereby making it possible to simulate the inertial load of a tracked vehicle when turning.

Unlike a wheeled vehicle, which is steered by turning the front wheels in the desired direction, tracked vehicles use a method called pivot steering. In pivot steering, the driver makes a turn by increasing the speed of the track on one side of the vehicle while decreasing the track speed on the opposite side.

NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

"Except for the bumping and jouncing that occur when passing over terrain, and a slope test required for brake tests and for detecting fuel leaks, the PAISI can subject a vehicle to everything it would experience on a real test track," Cargo asserted.

Cargo said that the PAISI will greatly expand the Mainz Army Depot's capacity to test rebuilt vehicles. He said its current capacity is severely limited because the facility's vehicle test track is too small to adequately test today's combat vehicles.

Noise Factor Reduced

Moreover, the track is situated in a residential neighborhood and can only be used during daylight hours.

"The PAISI will allow Mainz to meet its testing requirements and at the same time minimize its road requirements," Cargo said.

Noting other advantages over conventional test procedures, Cargo said, "The system will result in significant cost savings—both in terms of manpower and track wear. Furthermore, Mainz will be able to run the test stand 24 hours a day, with absolute security and without the problem of offending the neighborhood.

"Also," he added, "the tests will be totally objective. When vehicles are driven on a test track, the results are not objective, because they depend to some extent on external variables such as how the driver feels or what the weather is like. But with the PAISI, these external variables can be eliminated."

Installation of the Mainz tester is slated for completion in 1986. It will be capable of testing vehicles weighing up to 25 tons, including the M2/M3 Bradley vehicles.

Second Facility Likely

According to Cargo, if this first unit proves to be a success, a second PAISI is planned for Mainz that will be large enough to test vehicles with horsepower and weight greater than the current M1 Tank.

He said plans are under way to buy a highly sophisticated variant of the Mainz inertia simulator for TACOM's vehicle test cell in Building 212.

Said Cargo, "The TACOM system would give us the capability of taking every truck, tank and heavy equipment transporter and establishing base line operational characteristics for each. Then we would be able to objectively check random vehicles off a production line or rebuilt vehicles and compare their performance with these baselines."

Cargo added that for new vehicle development, the proposed PAISI system would also be capable of testing and validating power train components—engines, transmissions, etc.—with inertia simulation for the anticipated weight of proposed future vehicles.

PAISI TEST OF GERMAN ARMY TANK AS SEEN FROM CONTROL ROOM

Stack Manufacture Unfeasible

TFT Display Design Complete

by

Robert Miller
U. S. Army Communications & Electronics Command

Multiple thin film layers of approximately 44 thicknesses were proven unfeasible for pilot line scale of production of integrated transistor displays by an MM&T project conducted by Aerojet ElectroSystems for the U.S. Army R&D Command. A major finding of this program was that the roughness of each surface is replicated and amplified as more layers are added. Control of this roughness will require more materials process research—material changes and tooling changes.

A thin film transistor electroluminescent display design meeting Army needs was completed. A pilot line was set up and demonstrated. The basic device was from four stacks: electroluminescent stack, counter electrode stack, thin film transistor stack, and addressing stack. Each of these stacks could be made on the pilot line and tested to confirm proper operation. However, all the stacks could not be built upon each other monolithically and operate properly.

It was concluded that the overall process is not sufficiently mature for a pilot plant operation. The unforeseen problems experienced on this program relating to surface morphology interaction render the present approach to making monolithic multiple thin film layers of this magnitude unfeasible without further research and development.

Pilot Line Effective in Principle

This article describes the results of the MM&T program to develop an electroluminescent display in which the addressing makes use of thin-film transistors at each pixel. The display was specifically designed to be made on a pilot production line using all additive processes. The pilot line was shown to be effective in principle since it did accomplish limited groups of processes well, though it would not accomplish the entire series of processes required to produce an electroluminescent panel with functioning thin-film electronic drivers. This major finding with the present process relates to the replication and amplification of nonuniformities through successive film layers.

In accordance with program guidelines, the displays were to have an overall size of less than 4 inches by 8 inches and contain a minimum of 77 rows by 222 columns that were matrix addressable for alphanumeric and graphic data. Additionally, the display was to have memory, and to be low in power, lightweight, rugged, and sunlight readable. (See Table 1)

NOTE: This manufacturing technology project that was conducted by Aerojet ElectroSystems was funded by the U.S. Army Electronics R&D Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The ERADCOM Point of Contact for more information is Bob Moore, (202) 394-3812.

During this program at AESC two pixel designs were completed and studied in detail. The first was fabricated as a pixel array of 38 rows by 49 columns on a 2.5 inch by 2.5 inch glass substrate as shown in Figure 1. Once perfected, the matrix was to be expanded to full size as shown in Figure 2. The expanded version would be made from four quadrants. A quadrant before edge trimming is shown in Figure 3. The second design was fabricated as a pixel array of 80 rows by 224 columns on a single 2.5 inch by 5 inch glass substrate. The array was made for 80 rows by 224 columns to allow for extra test rows and columns on the perimeter. An actual photograph of the electroluminescent display is shown in Figure 4. This design met all the geometric requirements of the ultimate device on a single substrate.

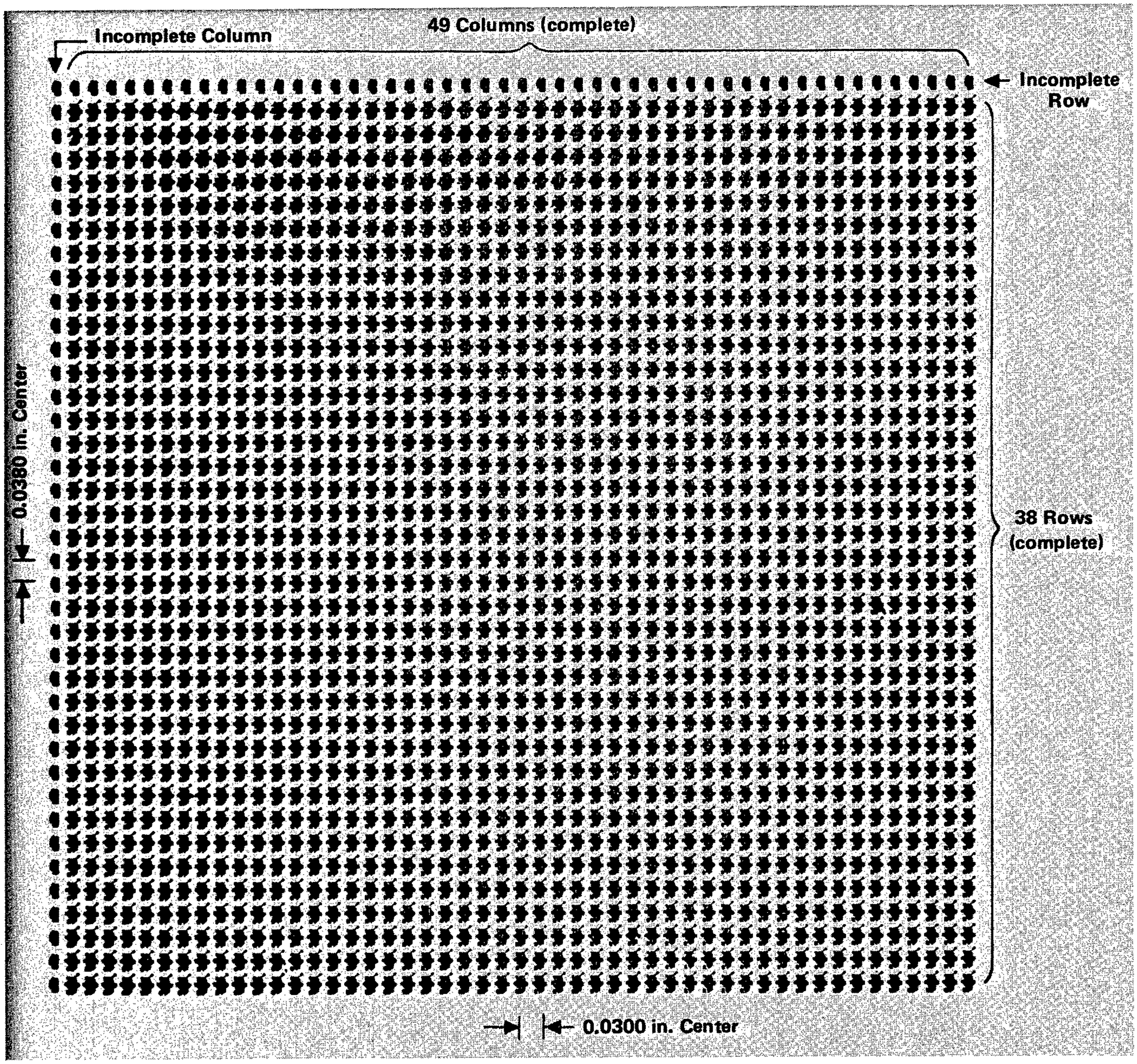


Figure 1

TFT Advantages	Application To EL	Application to LC and Other Nonemitters
Switch at Each Pixel	Not Needed, But Advantageous	Mandatory For Matrix Addressing
Memory	Advantage For 100% Duty Cycle	Mandatory For Matrix Addressing
High Voltage	Definite Advantage. H. V. Line Driver Only Option	Not Needed At All
Large Area	No Advantage	Advantage Over MOS
Low Cost	Must Be Lower Than H. V. Line Drivers	Must Be Lower Than Optional MOS Switch

Table 1

Design Goals Revised

A third design was completed up through mask fabrication with a limited number of thin-film transistor stack fabrications. This design was set aside while detailed problems were being worked out on the first design. After the problems were resolved, it was concluded that a new design was justified, which led to the creation of the second design.

The lack of complete success was indeed frustrating for several reasons. As the films accumulated, the roughness would be multiplied until the size of the anomalies exceeded the thickness of the succeeding thin film. At this point the performance would become erratic. This was then compounded by the internal electric fields applied to the phosphors, semiconductors and dielectrics which were as high as 2MV/cm. Any pinholes at these field strengths would arc and destroy the entire film in the vicinity of the arc.

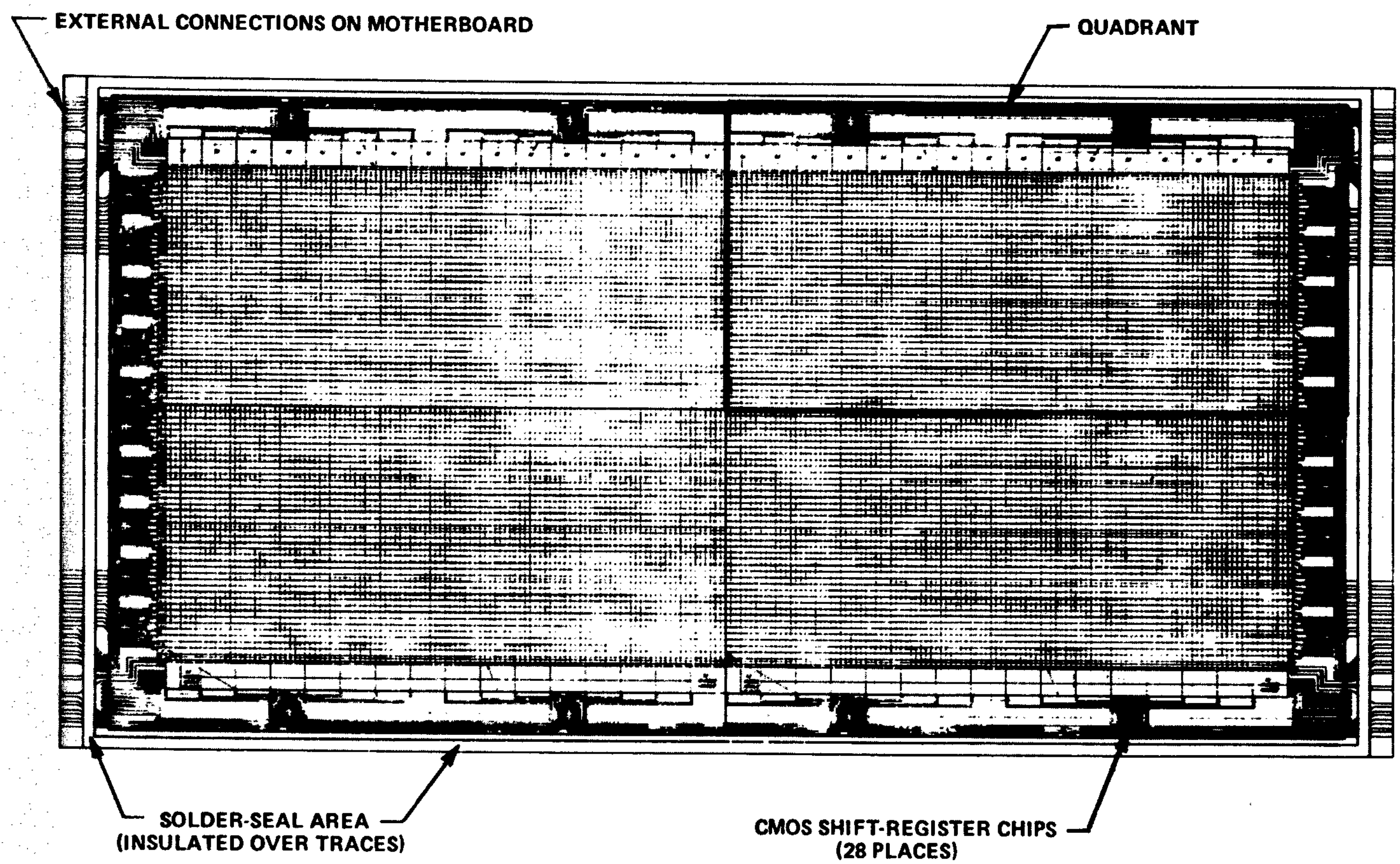


Figure 2

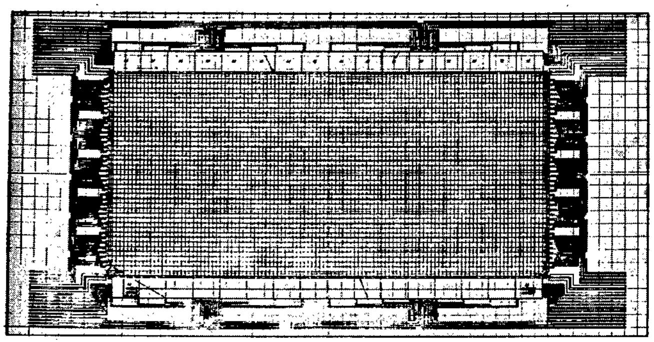


Figure 3

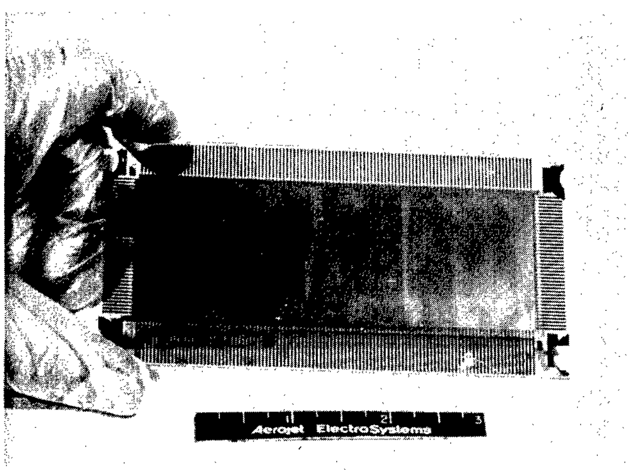


Figure 4

Thin Film Transistors

The thin-film transistor, invented in 1962 by Dr. P. K. Weimer at RCA, is a unique kind of transistor in that it can be made on a low-cost substrate such as a glass or polymer. As yet, however, there is no component in production using thin-film transistors, because of

- Successes in MOS FETs
- Technical problems in reproducibility
- Lack of a critical need heretofore.

A critical need now does exist in direct view flat-panel electronic displays. The successes in MOS have further accentuated the lack of low-cost low-power, lightweight flat-panel displays that are compatible with the new line of LSI microprocessors, memories, switching power supplies, etc. The technical problems with thin-film transistors are not significant for the flatpanel display application. The best approach is to keep the thin-film transistor circuits simple and the dimensions large.

Flat-Panel Displays Matrix Addressed

Flat-panel displays have a unique requirement in that they must be matrix addressed. Matrix addressing inherently produces "sneak" circuits, which cause at least one-third of the select voltage to be applied across all the nonaddressed pixels. Additionally, gas discharge and electroluminescent display technologies require a higher operating voltage than is readily available with MOS. Also, flat-panel displays can benefit from memory storage at each pixel. The memory allows for a 100 percent duty cycle. Without memory, the duty cycle and brightness are inversely proportional to the number of display array rows. The thin-film transistor circuit at each pixel eliminates sneak circuits, provides the necessary voltage gain to stimulate the display media, and facilitates the incorporation of memory elements.

Thin Film Transistor Stack

This transistor is more sophisticated than that developed by Dr. Weimer, in that it uses dual gates as shown in Figure 5. Dual gates provide sharper turn-off characteristics and a high β coefficient (geometric factor). The pixel circuit uses two thin-film transistors and a capacitor for display memory.

Fabrication techniques used are:

- Deposition of materials through chemically etched Kovar metal masks
- Ball-and-race aligned tooling set for mask and substrate registration
- Magnetic pulldown for mask clamping to substrate
- Tool and mask carousel for in-chamber interchange
- A three-chimney vapor vacuum-deposition chamber.

The thin-film transistor is a perfectly symmetrical electrical device if the source-to-gate geometry is identical to the drain-to-gate geometry. That is to say, the drain and source can be interchanged. The grounded electrode is the source. When the thin-film transistor is turned off by making the gate slightly negative, it has the electrical properties of a switch with low leakage.

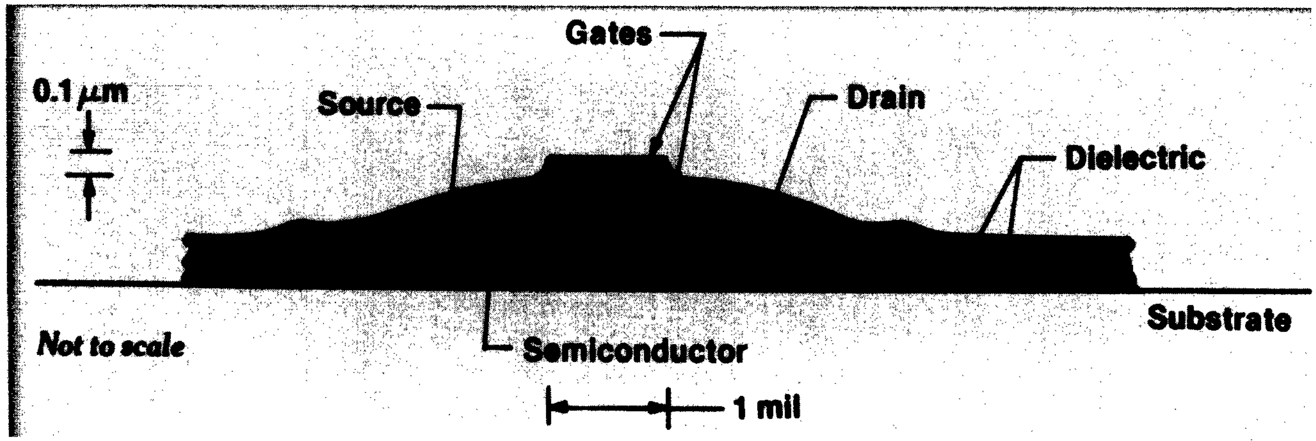


Figure 5

Counterelectrode Stack

The counterelectrode stack contains a capacitor used in series with the the electroluminescent capacitance for voltage division. It provides sufficient voltage drop that the pixel will not light. The second thin-film transistor shorts out the divider capacitor to turn on the pixel. When the divider capacitor is shorted out, the full voltage is applied across the electroluminescent thin film, which is electrically equivalent to a capacitor to a first approximation.

Electroluminescent Stack

The electroluminescent stack is built first on the substrate. The material is ZnS with Mn/Cu as the primary activator. The stack is optimized for steep brightness-to-applied-voltage performance. Brightness control is easily achieved with power frequency control.

A display with the electroluminescent performance is easily made sunlight readable. Since thin-film ZnS is transparent, the use of a black light-absorbing back layer or a reflecting back layer with front circular polarizer is applicable to achieve sunlight readibility.

Addressing Stack

The addressing stack contains the row and column lines and accommodates the crossovers. The row and column lines are extended to the edge of the glass substrate for external drive at MOS level voltages.

TFT-EL Display

The process profile for fabricating the display is outlined in Figure 6. Two basic approaches considered for connecting the thin-film transistors to the electroluminescent are monolithic and sandwich, as shown in Figure 7.

Electroluminescent display is the most efficient light emitting except for the cathodoluminescent techniques. The electroluminescent panel has a high imaginary power component which cannot be easily saved.

Design Problems Encountered

Design No. 1 had four major process problems:

(a) A hole had to be ion milled through the counter electrode stack and back filled with metal to connect the thin-film transistor with the electroluminescent pixel area electrode. This required a resist photolithographic step, an ion milling step, a metal deposition step and a resist removal step. The wet processing usually caused contamination of the substrate.

(b) A thick insulating film had to be used in the addressing stack to prevent capacitive coupling between row and column lines. It was hard to apply repeatedly and etch without causing contamination to the thin-film layers.

(c) The metal in-contact mask design did not allow for any error in alignment that may arise due to thermal expansion, wear, tooling variations, etc.

(d) The complete set of four stacks had too many thin film layers, which added to the morphology problem discussed above and reduced the yield probability.

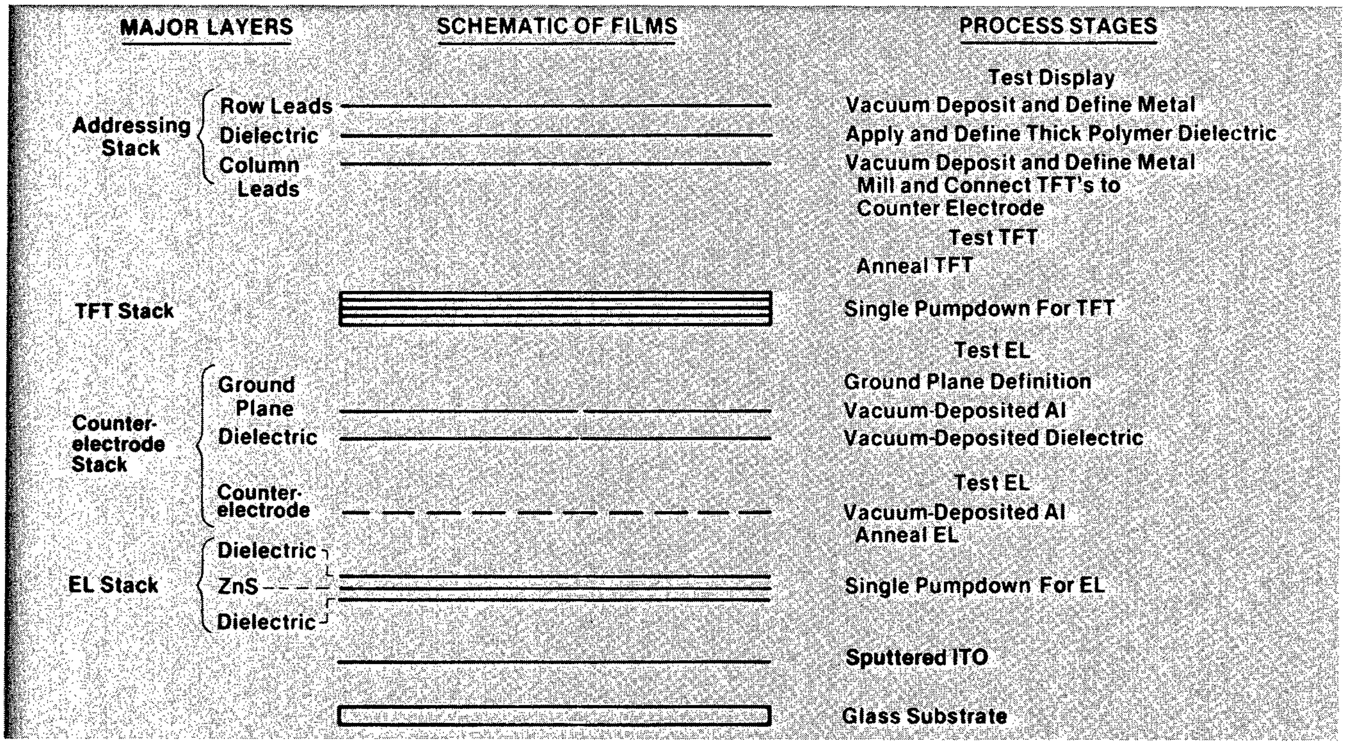


Figure 6

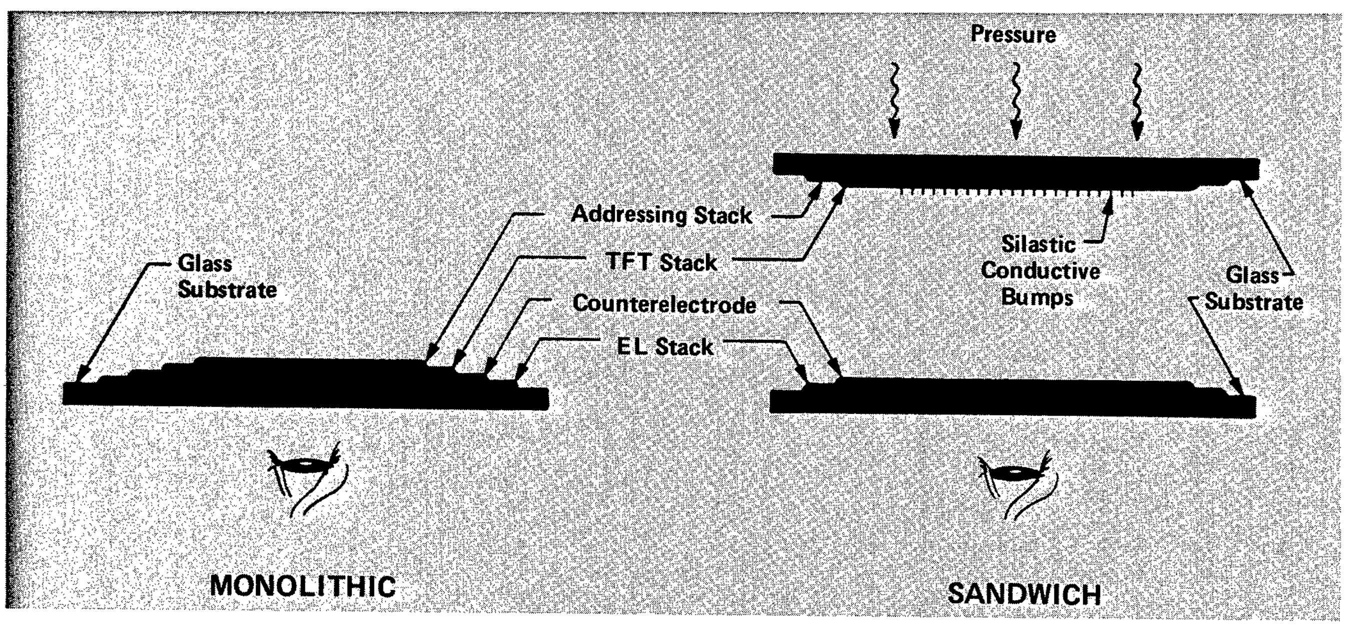


Figure 7

Design No. 2 More Effective

All the problems of Design No. 1 except (d) were eliminated in the redesign: (a) the stacks were made all additive. By using overlapping additive mask deposition the need to ion mill was eliminated. (b) All the layers were made additive including the addressing stack. The capacitive coupling was minimized through geometric design of overlapping areas. (c) An allowance of one mil of motion relative to all other masks was built into each mask during its design, except alignment between gate mask and source-drain mask. (d) The number of thin film layers was reduced, but not enough to completely eliminate the morphology problem.

The quadrant approach was abandoned. All the rows and columns needed were designed onto a single 2-1/2 in. x 5 in. substrate. This greatly simplified the overall assembly. The resolution was increased to approximately 50 lines per inch, which was considered quite acceptable for the Army applications.

PROBLEMS FOR PILOT SCALE PRODUCTION

Mask Alignment Heat Induced Error

The alignment of substrate to in-contact masks is difficult and sensitive to thermal changes.

Dielectrics are superior when deposited on substrates which are heated to 300 C or higher to avoid voids in the thin film columnar growth structure.

When heat is applied to a substrate approaching 300 C, large shifts occur in the pre-aligned metal mask position resulting in a significant misregistration of the pattern. Further, in order to provide radiant heating from quartz lamps, the magnetic clamping device which maintains intimate contact between the masks and substrate must be removed, resulting in potentially additional misregistration of the deposited pattern when reengaged. The magnets themselves lose magnetism at 300 C.

A compromise in heating for dielectric depositions was used. The alignment was preserved; however, the dielectric undoubtedly had more voids and the surface was undoubtedly rougher. The rougher surface was amplified up through each dielectric layer, contributing further to the ultimate weakness of the process.

Annealing

The thin-film transistors need to be annealed at 350 C for eight hours, or 400 C for three hours at a minimum. At either of these annealing profiles the preferred proprietary black layer would delaminate. Successful annealing could not be achieved at 300 C. This problem has not been resolved to date.

Conclusions

A final design was achieved which satisfied the program guidelines. A pilot line was set up which produced the display at an acceptable rate; however, the resulting displays did not operate satisfactorily.

A compounding of surface roughness through successive thin film depositions caused the final surfaces to be too rough to perform without breaking down electrically. This is one of the major findings of this program. Further reseach is necessary to eliminate the excessive roughness.

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(2) P. K. Weimer, "Handbook of Thin Film Technology", edited by L. I. Maissel and R. Glang (McGraw-Hill, New York, 1970), Chapt. 20.

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New System Faster

Cheaper Welds for the M1 System

By George Taylor
U.S. Army Tank—Automotive Command

A project involving TACOM and Avco Lycoming has led to the development of a laser welding system which the Army hopes will save some $3.5 million in production costs for a key M1-series tank engine component.

The project is part of a larger Department of Defense-wide effort called the Manufacturing Methods and Technology (MM&T) program.

The aim of this program is to improve the quality of military equipment and reduce its production costs whereever possible by applying the latest technological advances to develop improved manufacturing methods.

The M1's 1500 hp Avco Lycoming gas turbine engine uses a heat exchanger, commonly called a recuperator, that improves fuel economy by using exhaust-gas heat to preheat the incoming air before it enters the engine's combustion chamber.

This recuperator is a 22-inch-long unit consisting of 560 welded annular plates made of a nickel-based superalloy material. Each plate has an outside diameter of 27 inches, a 15-inch inside diameter, and is 0.008 inches thick.

The plates each have a pattern of ellipitcal- and triangular-shaped holes which serve as inlet and outlet air passages.

In assembling the unit, the plates are first welded in pairs around each of the holes. These plate pairs are then stacked on top of each other and alternately welded along their inside and outside edges.

The first 600 or so recuperators were assembled entirely with the standard resistance-welding method. In resistance welding, a high electric current passes from an electrode to the metal being welded. As the current flows through the metal, it encounters a considerable amount of resistance, which produces enough heat to fuse the metal.

But this approach proved to be expensive and time-consuming due to the complex nature of the welding. An alternate welding method was needed.

Laser Welding Introduced

So, late in 1982, following a three-year development effort that included both dynamometer and vehicle tests of laser-welded heat exchangers, Avco Lycoming began laser-welding the air passages—the most difficult part of the assembly operation.

In laser welding there are no electrodes. Instead, the metal is exposed to a high-energy laser beam which, in a matter of a few seconds, creates the intense heat needed to complete a weld joint.

The laser welder uses two 525-watt laser units, each having a computer-controlled moving mirror system that directs the laser beam to individual welding sites.

In addition, the machine has two work stations. Each includes a rotary positioning table and a fixture that are controlled by a robotic swing arm load/unload system shared between the laser stations. The welding units run out of phase, so that while one of them is welding the other is being loaded and unloaded.

Invisible Magic

"The only thing that touches the metal during the welding operation is the fixture that holds it in position," said David J. Pyrce, TACOM R&D Center engineer who heads the M1 recuperator welding project.

NOTE: This manufacturing technology project was funded by the U.S. Army Tank-Automotive Command under the overall direction of the U.S. Army Manufacturing Technology Program office of the U.S. Army Materiel Command (AMC). The TACOM Point of Contact for more information is Don Cargo, (313) 574-8709.

"To someone not familiar with lasers," he added, "it looks like the machine is welding by magic, because the laser beam is invisible to the naked eye."

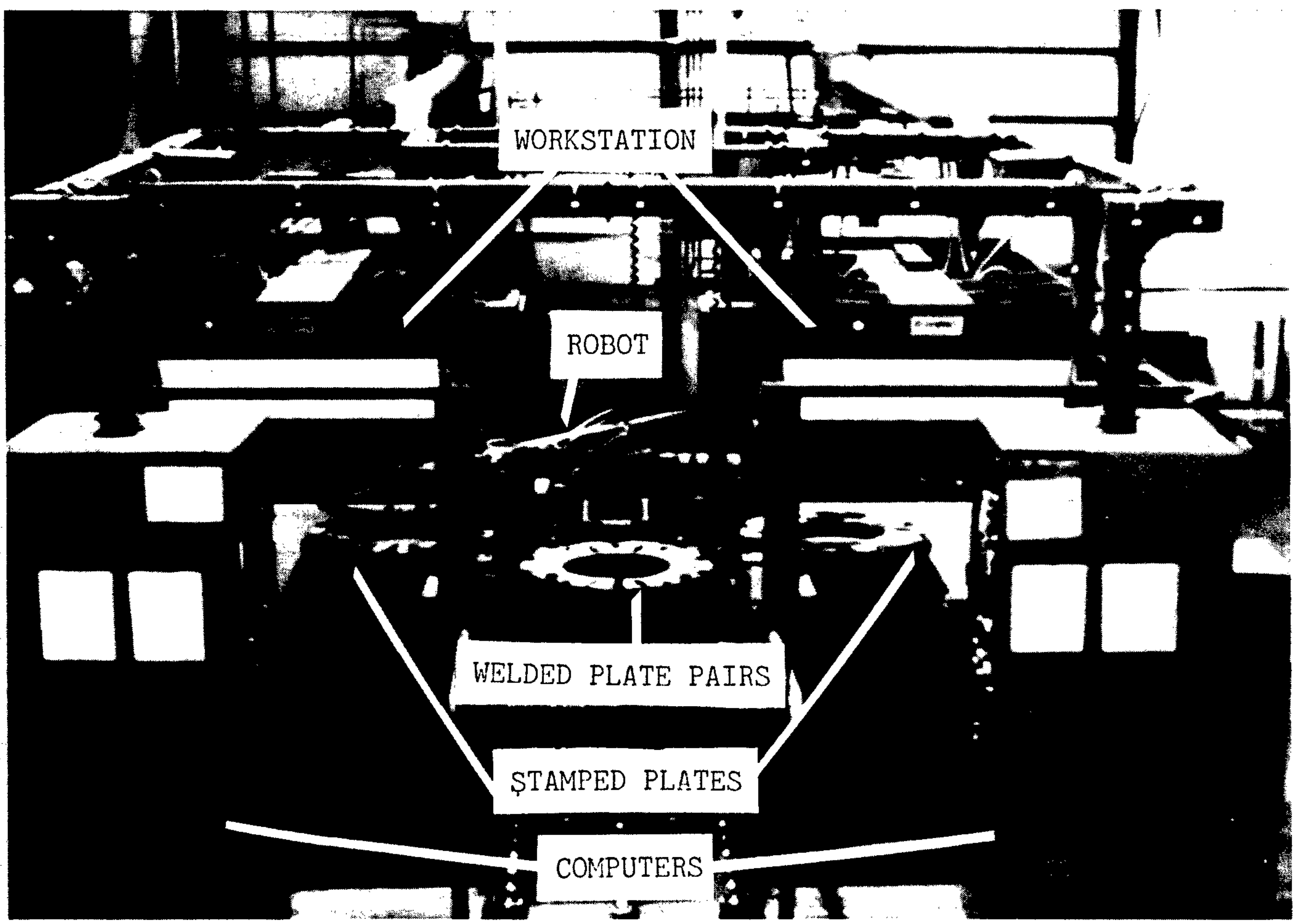
Noting advantages of the laser procedure over standard resistance welding, Pyrce said the new system welds at a rate of 90 inches per minute—nearly twice as fast as a conventional welder.

Less Labor Intensive

Additionally, he said production costs are less because the automated equipment makes the laser technique less labor-intensive. "It takes only one man to operate it, while the resistance welder requires three men," he said.

When asked if laser welding has other potential military vehicle applications, Pyrce said, "We hope someday to begin doing the remaining welds at the inner and outer edges of the heat exchanger plates with the laser.

"Also," he continued, "we have another MM&T project under way to investigate the possibility of laser-welding vehicle armor. We see a great potential here—particularly for welding the long, flat joints in vehicle hull floors and sides, where warpage during arc welding currently causes a lot of problems."



LASER WELDING SYSTEM FOR THE AGT-1500 TURBINE RECUPERATOR

616 T